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Numbers 1, 2 and 3 of Volume 2 were edited by George S. Myers; Numbers 4, 5 and 6, and the Index were edited, during Dr. Myers' absence in Brazil, by Margaret Storey.

CONTENTS

[New generic and specific nam . .re marked with an asterisk (*).]

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AGE, LENGTH, AND WEIGHT STUDIES OF THREE SPECIES OF COLUMBIA RIVER SALMON (*ONCORHYNCHUS KETA, O. GORBUSCHA,* AND *O. KISUTCH*)[1]

By John C. Marr

INTRODUCTION

The salmon runs of the Columbia River have held an important place in the economic structure of Oregon and Washington since the beginning of their exploitation in the 1860's. The fishing intensity has increased constantly. The reduction of spawning areas, brought about by the construction of dams and other developments of water resources, have acted unfavorably to modify natural conditions and the productivity of the fisheries. These threats to a valuable natural resource have stimulated investigations into the biology of the fishes entering the commercial catch, because such knowledge is of primary importance in an intelligent conservation program. The fishes include the salmons of the genus *Oncorhynchus* and the steelhead trout. In the commercial fishery of the Columbia River the Chinook (elsewhere called Tyee, spring, Quinnat, or king) salmon, *O. tschawytscha* (Walbaum), is of first importance; followed by the steelhead (rainbow or salmon trout), *Salmo gairdnerii* Richardson; the blueback (sockeye), *Oncorhynchus nerka* (Walbaum); the silver salmon (coho), *O. kisutch* (Walbaum); and the chum (dog) salmon, *O. keta* (Walbaum). Pink (humpback) salmon, *O. gorbuscha* (Walbaum), are rarely seen, and do not occur in sufficient numbers to be of commercial importance.

It has been shown by Rich (1942; 1943) that the Chinook runs are seriously depleted. The blueback runs have been decreased greatly, but have stayed at a fairly constant level since 1900. The trend of the catch of silvers and chums has been upward in recent years, but this has been due to an increased fishing intensity for these species, as the availability of Chinooks and bluebacks has been reduced, rather than to an actual increase in the abundance of the less valuable species. Silvers and chums, since they spawn in the lower tributaries, have suffered relatively less from the destruction of spawning beds, in contrast with the Chinooks and bluebacks, which ascend to the higher reaches of the river system. Under these conditions the silvers and chums will probably become increasingly important in the commercial fishery. In previous investigations of the biology of the Columbia River salmons these two species have been relatively neglected in favor of those of greater commercial importance. As a basis for sound management, it is now pertinent to go more thoroughly into their life histories.

[1]Contribution No. 9, Department of Research, Fish Commission of Oregon.

Materials and data on chums, pinks, and silvers which can be utilized for this purpose were collected during the year 1914 by W. H. Rich. These consist of scales, length and weight measurements, and sex determinations, for a series of samples taken at random from the commercial catch, and have been used here for a preliminary study of the relationships between age, weight, length, and sex. A knowledge of these phases of the biology of the salmons is essential as a foundation for the more extensive studies of the fishes and fisheries that should form the basis for conservation methods; studies which should include consideration of racial characteristics, growth rates, sex ratios, variations in size, age, and sex ratios during the course of a run, and other related aspects of fisheries biology.

The materials and data on which this paper is based were taken consistently in all of the collections: the scales were taken from the mid-lateral portion of the fish, just above or just below the lateral line; length was measured to the nearest whole centimeter, with a tape over the body from the tip of the snout to the distal end of the middle caudal rays; weight was measured to the nearest whole ounce, on a spring scale; sex was determined by inspection of the gonads.

ACKNOWLEDGMENTS

Thanks are due Mr. O. E. Sette and Dr. L. A. Walford, of the U.S. Fish and Wildlife Service, South Pacific Investigations, located at Stanford University, for the privilege of using their scale projector and for valuable suggestions. Mrs. Louise M. Marr rendered valuable assistance. Finally, I am indebted to Professor W. H. Rich, of Stanford University, not only for the material on which this study is based, but for his always available advice and encouragement.

CHUMS

During the last fifty years much information has been accumulated about the salmons, but very little is known about the chum salmon in particular. Evermann and Goldsborough (1907) gave length and weight measurements on Alaskan specimens. Chamberlain (1907) described the appearance of the fry and fingerlings from Alaskan material. McMurrich (1909; 1912; 1913a; 1913b) attempted to interpret the life history of chums by scale examination. Gilbert (1913a) described accurately for the first time, on the basis of scale examinations, the general features of the life history of Puget Sound chums. Further contributions to the knowledge of the chum have been made occasionally since then, notably by Gilbert (1922) on material from the Yukon River; Fraser (1916b; 1920; 1921) and Pritchard (1932; 1943) on fish taken in the Gulf of Georgia; and Rounsefell and Kelez (1938) on Admiralty Inlet specimens. Catch data for Columbia River chums have been presented by Craig and Hacker (1940) and by Rich (1942). The latter has also included information on the nature of the run. All of these accounts are limited in scope. So far as is known, no comprehensive report on the biology of the Columbia River chum salmon has been made.

The samples used in this study were taken from the commercial catch on October 13, 22, 23, 30, 31, and November 16, 17, and 20, 1914. This period does not cover the entire chum run, which lasts from early October to late December, but does include the peak. In fact, roughly 90 per cent of the total run occurs between October 15 and November 20 (Rich, 1942: 110). Of the total sample, 91.3 per cent were taken by gill nets in the lower Columbia River and landed at Ilwaco, Washing-

ton. The remaining 8.7 per cent represents fish taken in traps, all from the lower Columbia River near the mouth of the Chinook River. Those taken in traps presumably represent a random sample of the run. While it is true that gill nets are selective, it must be remembered that they are used with the intent of catching as many fishes as possible. The practical fishermen know, of course, the approximate size of the fishes constituting the major part of a run at any given time, and provide nets with mesh of the most efficient size. It follows, therefore, that the samples from the gill net catches, in addition to being typical of that part of the commercial catch, approach a true representation of the most abundant size and age groups. In these samples there will be a tendency for the smaller and younger and the larger and older fish to be inadequately represented in relation to the entire run; but it is a reasonable assumption that the samples fairly represent the commercial catch.

AGE AND LENGTH.—Ages were determined from the scales by accepted methods of interpretation. Fish scales have long received much attention and, from the time that Johnston (1905) first examined salmon scales with reference to age determination, much has been written on the subject; therefore it is not necessary to go into the matter here. Detailed information on the scales of the Pacific salmons is given in Gilbert's (1913a) paper on the subject. Discussions of the scale method in general and extensive bibliographies are given by Creaser (1926) and Van Oosten (1929).

Two pairs of scale readings were made; each scale was read at least four times. All readings were made without reference to the length or weight of the fish. The first pair of readings was made with a compound microscope. The scales were read once, and later reread without reference to the previous reading. Then the results were compared. If the two readings of a scale did not agree or were recorded as doubtful, the scale was examined a third time, and a final decision reached as to the most probable age. After this set of readings had been completed, a device became available which projects an enlarged image of a scale by means of mirrors used in conjunction with a compound microscope. With this instrument, a second pair of readings was made as an additional check on age determination. Each reading was made without reference to any preceding readings. Again, disagreements and doubtful determinations arising in this pair of readings were reviewed; then a final decision was made as to age.

Disagreements occurred in 12.6 per cent of the total number of scales read (518) in the first pair of readings (made with the microscope), and in 9.1 per cent of the total number of the second pair (read by projected image). About half of the disagreements were common to both pairs of readings; and the same final decisions were reached for slightly less than half of these common disagreements. Under ideal conditions, the same age should be observed upon successive readings of a given scale; this was the case with most of the chum scales studied. The disagreements and doubtful age determinations that did arise upon successive readings were due almost entirely to scales which had prominent "accessory checks" (i.e., irregularities in the spacing of the circuli that simulate annuli). Accessory checks inevitably increase the variation in age determination due to personal interpretation. Since, however, chum scales in general are easily read, it is felt that fairly accurate age determinations were made. The results of the second pair of readings (by projected image) have been used here, because of the closer agreement between successive readings.

It is known that chum salmon migrate to sea very soon after they become free swimming; their scales show only the record of oceanic life. This was observed in the samples studied. Ages of three, four, and five years were recorded. No grilse

Fig. 1. Chum: scale from a three-year-old male, 74 centimeters long, taken in the lower Columbia River on November 20, 1914.

Fig. 2. Chum: scale from a three-year-old female, 71 centimeters long, taken in the lower Columbia River on November 16, 1914.

Fig. 3. Chum: scale from a four-year-old male, 88 centimeters long, taken in the lower Columbia River on October 22, 1914.

Fig. 4. Chum: scale from a four-year-old female, 77 centimeters long, taken in the lower Columbia River on October 22, 1914.

Fig. 5. Chum: scale from a five-year-old male, 82 centimeters long, taken in the lower Columbia River on October 13, 1914.

(two-year-olds) were found. Figures 1 to 5 are photographs of representative scales of all sex-age categories.

After the ages had been satisfactorily determined, length-frequency distributions were prepared for each ultimate category defined by a single age, sex, method of capture (gill net or trap), and date of collection. The "gill net" distributions were then examined for heterogeneity by means of analysis of variance (see Snedecor, 1934).

There was some indication that the length of the three-year-old males varied significantly with time: collections taken in November had a relatively higher proportion of individuals 70 centimeters or shorter than did those taken in October. The six distributions involved were therefore combined into two, defined by month of capture, and the difference in the means of these two distributions was tested for significance by the usual t test (Snedecor, 1937: 52). The difference was 2.41 centimeters, and the standard error of the difference of the means was 0.84. The probability that this difference would be exceeded by chance is less than 0.01; but, since this condition was not observed in any of the other sex-age classes, it seems possible that this one instance has been due to the unintentional sampling of a catch from a smaller mesh net than was generally used. The several groups were therefore combined into a single frequency distribution.

The three-year-old females and the four-year-old males were all shown, by analysis of variance, to vary to a greater extent within the means of the date classes than between the means of the date classes; the separate length-frequency distributions of these two groups were accordingly combined to form one distribution for each sex-age category.

Comparison of the four-year-old female distributions indicated that there may be a significantly greater variation between the means of the date classes than within the means of the date classes. The F value obtained through analysis of variance lies approximately at the 3 per cent level of significance. Inspection of the distributions showed no trends except a tendency for longer fish to be taken on October 23 and 30 than on the date preceding and on the dates following. No explanation for this apparent tendency is available; and, since it was not evident in other age classes, it was decided to combine all date classes into one distribution.

Since the total number of fish in the "trap group" was only 45, it was not practical to examine them for heterogeneity. However, it was seen by inspection that these distributions agreed well with those of the gill net fish. Consequently, trap and gill net fish were combined.

The resulting length frequencies, grouped by sex and age without reference to date or method of capture, are shown in Table 1. As would be expected, older fish are seen to be significantly longer than younger fish, and males are significantly longer than females. This provides an indirect confirmation of the accuracy of the scale readings; groups of fish that were considered to be homogeneous for age are independently shown to be homogeneous for a related characteristic, namely, length.

As can be seen in Table 1, the major portion of the run consisted of three-year-old fish; 70.5 per cent of the total were three years old, 28.7 per cent were four years old, and 0.8 per cent were five years old. It is possible that these percentages might have been somewhat different had samples been taken over the entire run. A discussion of this is included below in the consideration of the changes occurring during the course of the run.

GROWTH.—In the course of reading scales for age determinations, data were obtained that are useful in determining the growth rate of the chum salmon. When

Table 1. Length-frequency distributions of 518 chum salmon from the Columbia River, 1914, grouped by sex and age

Length in cm.	Three-year-old ♂	Three-year-old ♀	Four-year-old ♂	Four-year-old ♀	Five-year-old ♂
60		1			
1					
2		1			
3		1			
4		3			
5		3			
6	3	13		1	
7	4	11			
8	1	17		3	
9	4	24	1	1	
70	3	28	1	5	1
1	8	23	1	4	
2	10	19		2	
3	14	16	3	5	1
4	20	9	4	7	
5	11	4	2	4	
6	24	4	4	8	
7	21	1	9	15	
8	19		5	6	
9	16	1	4	3	
80	7		5	2	1
1	8		7	2	
2	10		6		1
3	1		4		
4			7		
5			4		
6			3		
7	1		5		
8	1		3		
9					
90					
1			2		
2			1		
Means..........	75.85	70.02	80.59	74.85	
Standard deviations.....	4.05	3.06	5.51	3.89	
Number.........	186	179	81	68	4
Per cent of total number...	70.5		28.7		0.8

the age was read from the projected image, the relative position of the center of the scale "nucleus," the margin of each year's growth, and the periphery of the scale were marked on slips of paper; and the distances from the center to the margin of each year's growth were later measured. These scale measurements may be considered to be in arbitrary units, which is permissible since actual size is not of direct importance. All measurements were made with the same degree of magnification, and the units used were actually equal to 0.0$\dot{3}$ millimeters. The measurements were made as consistently as possible along a line in the anterior quadrant of the scale, perpendicular to the axis formed by the juncture of the exposed and covered portions of the scale. The anterior quadrant was used in order to eliminate any variation that might arise from measuring radii without respect to a particular region of the scale. Furthermore, the annuli were generally more clearly defined in this region. The terminal portion of the scale was missing in a few instances (4), and these scales were discarded in making the growth study, although it was possible to make accurate age determinations from them. Particular attention was paid to the possibility of the absorption of scale margins, a characteristic of all sea-run salmon shortly after they enter fresh water. An excessive amount of absorption would result in errors in scale measurements, and in the calculations based on them. Absorption was noted in a few cases, but was not far advanced. The net effect seemed to be only the obliteration of a few terminal circuli on the surface of the scale; the margin apparently remained intact.

The method of utilizing such data was first described by Dahl (1911), and is based on the assumption that scale growth is proportional to fish growth throughout life. That is to say, $R_t:L_t=R_x:L_x$, where "R_t" is the total radius of the scale, "L_t" is the length of the fish when collected, "R_x" is the total radius of the scale at the end of any given year, and "L_x" is the length of the fish at the end of that given year. If this relation holds, as it does approximately, it is clear that the length of the fish at the end of any given year may be calculated from the other three measurements.

The assumption that scale growth is proportional to fish growth assumes that the scales start to grow as soon as the fish is formed. Actually, the scales do not appear until the fish has attained some length. Fraser (1916a) first made a correction for this differential growth, which may be expressed as $R_t:L_t-a=R_x:L_x-a$, where "a" equals the initial fish growth before scale formation. This method overcorrects for initial fish growth, since the scales actually grow faster when first formed than the fish does, as has been demonstrated in the sockeye salmon by Dunlop (1924), in the yellow perch (*Perca flavescens*) by Hile and Jobes (1941), and in other fishes.

Apparently, the relationship of scale radius to fish length is not linear, but curvilinear. As mentioned above, the fish attains some size before the scales are formed, and then, for a while, the scales grow relatively faster than the fish. However, the rate of scale growth soon becomes about the same as the rate of fish growth, and the two are practically equal for some time. Finally, in older fishes, the rate of fish growth exceeds the rate of scale growth, so that the scales become relatively smaller. This, again, has been pointed out in the sockeye salmon by Dunlop (1924). Hile and Jobes (1941) recognize this discrepancy in the yellow perch, but assume that it is negligible.

The true and the commonly assumed relationships between scale size and fish size are compared graphically in Figure 6. The line "OP" represents the relationship based on the assumption that scale growth throughout life is strictly proportional to the growth of the fish; while the curve "IJMT" shows the true relationship. The initial fish growth before scale formation is shown by "a." The line

"IF" takes into consideration Fraser's correction for initial fish growth; "IJ" similarly shows the effect of Hile and Jobes' correction for rapid early scale growth; "ML" the effect of the corresponding correction for the later, relatively

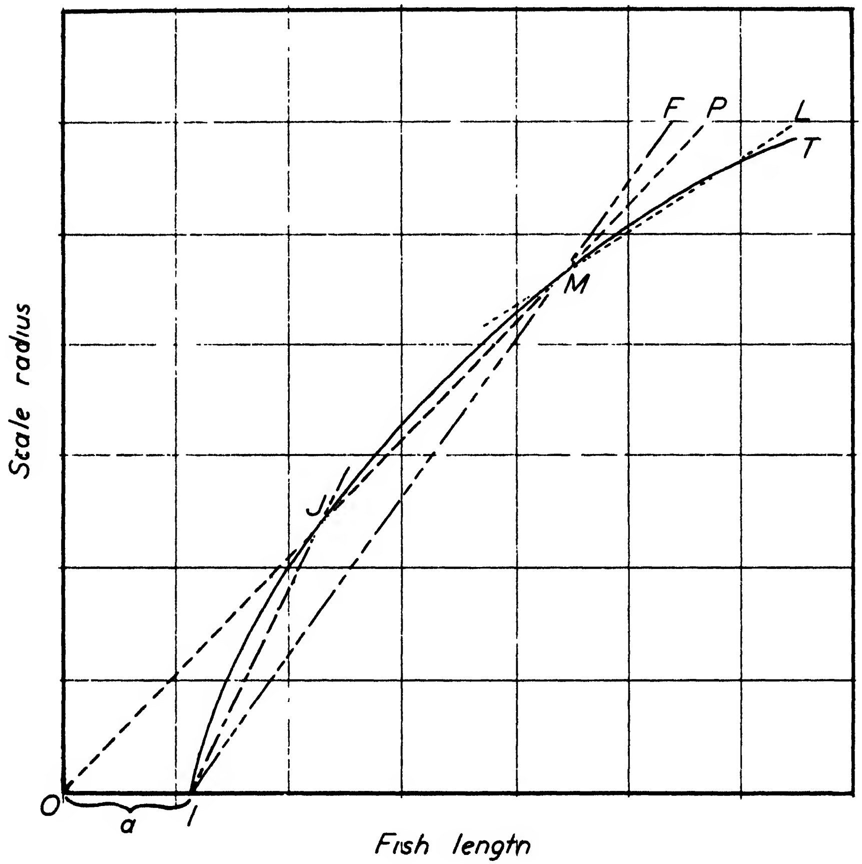

Fig. 6. Relation of scale growth to fish growth. The curve and corrections are generalized, representing no particular species. See text for explanation.

slow, scale growth; while the straight lines connecting the points I, J, M, and L give the resulting corrected "curve" combining the two corrections. The amount of correction commonly necessary, particularly for initial fish growth and rapid early scale growth, is exaggerated in the diagram. Dunlop (1924) found in the sockeye salmon that scale growth and fish growth became approximately proportional at a fish length of 7.1 centimeters.

If samples of chums covering the complete range in size were at hand, it would be a simple matter to obtain the "curve" IJML by calculating the regression lines IJ, JM, and ML. However, no chum fry and fingerlings are at present available, so that the line IJ, at least, cannot be determined. There is some evidence

that the rate of scale growth falls below the rate of fish growth in the older (larger) chums. That is, IJMT does fall below OP at their upper extremities. This can be shown by calculating the regression line of R/L on fish length, where "R" is scale radius, and "L" is fish length. For the data studied, this regression line is that of the equation $R/L = 1.45 - 0.0028 \times L$. If fish growth and scale growth were proportional, this regression line would be parallel to the X (length) axis, but its negative slope (downward to the right) indicates the disproportionate increase of scale length and fish length. Had females alone been considered, the slope would be somewhat less (see p. 168).

In spite of the fact that these corrections may be applied quite properly to Dahl's original method, the question arises as to whether or not, for practical purposes, they are necessary or even desirable. The differences obtained by the use of the several methods are slight in most salmons (and probably in most other fishes), except when lengths are calculated at such early ages as to involve the period previous to the time at which the scale size "catches up" with the fish size. (It is mentioned above that the differences are greatly exaggerated in Figure 6.) It is seldom of importance to estimate the size of salmons at very early ages, so that the correction for disparity between scale and fish growth in fry and fingerlings may be omitted ordinarily. Disporportionate scale and fish growth in larger chums has been demonstrated; but if the scale measurements are to be used only comparatively, the correction for this also may be omitted ordinarily. Mottley (1942) has pointed out that measurements of the scales of rainbow trout (*Salmo gairdnerii*) can be used directly as a measure of size, without making any of the corrections that have been used by other workers. Except for special purposes, it seems safe to use the simple, uncorrected method of Dahl, and this has been done throughout the present study.

It is well to point out, however, that, for the chum salmon at least, variation in scale length is relatively greater than variation in fish length. The coefficients of variation for scale radius and for fish length are 8.73 and 6.90, respectively. The standard error of the difference is 0.348. By a *t* test, the probability that this difference would be exceeded by chance proved to be less than 0.001.

Because fish lengths are calculated from scale measurements, the regression of fish length on scale radius is the correct one to use, instead of the regression of scale radius on fish length, which is generally used. The importance of this has been emphasized by Weymouth, McMillin, and Rich (1925).

As stated above, the calculation of lengths at earlier ages has been done by assuming the simple proportion $R_t : L_t = R_x : L_x$ to hold. The calculations were made by means of a ten-inch slide rule, which is sufficiently accurate for the purpose. From these calculated values, the common means of scale radius and fish length were determined for each year in each sex-age category. The means and the annual growth increments are presented in Table 2. The lines relating the means of scale size and fish size for each sex-age group are shown graphically in Figure 7. The line representing five-year-old males is probably not reliable, since only four fish are involved. In the other four lines, it will be noted that the ratio of scale radius to fish length (R/L) is consistently higher for females then for males, and consistently higher for younger than for older fish. To determine the significance of these differences, the ratio R/L was determined for each individual, and R/L frequency distributions were formed for the four sex-age groups. The actual known ratio (total radius to measured fish length) was used, because, on the assumption made, this ratio determines the rest of the line. The means and standard deviations, respectively, of these R/L distributions were: for the three-year-old males,

Table 2. Chums

Means of scale radius (R) in arbitrary units, fish length (L) in centimeters, and yearly increment (I) in centimeters at each age for each sex-age category. The terminal ("oldest") figures in the R and L columns represent actual size of scale and fish at time of capture sometime during the last year of growth, and are not necessarily, if ever, the end of the last year's growth.

Age	Three-year ♂ N = 184			Three-year ♀ N = 178			Four-year ♂ N = 81			Four-year ♀ N = 67			Five-year ♂ N = 4		
	R	L	I	R	L	I	R	L	I	R	L	I	R	L	I
End 1...	40.45	32.71	32.71	39.61	31.17	31.17	36.25	30.36	30.36	35.99	29.06	29.06	38.25	28.25	28.25
End 2...	72.32	58.67	25.96	69.12	54.39	23.22	63.35	53.03	22.67	61.13	49.43	20.37	65.50	48.75	20.50
End 3...	93.74	75.01	16.34	88.83	70.01	15.62	81.40	67.88	14.85	78.19	63.11	13.68	78.25	58.50	9.75
End 4...							96.73	80.59	12.71	92.58	74.87	11.76	90.00	66.75	8.25
End 5...													102.75	76.25	9.50

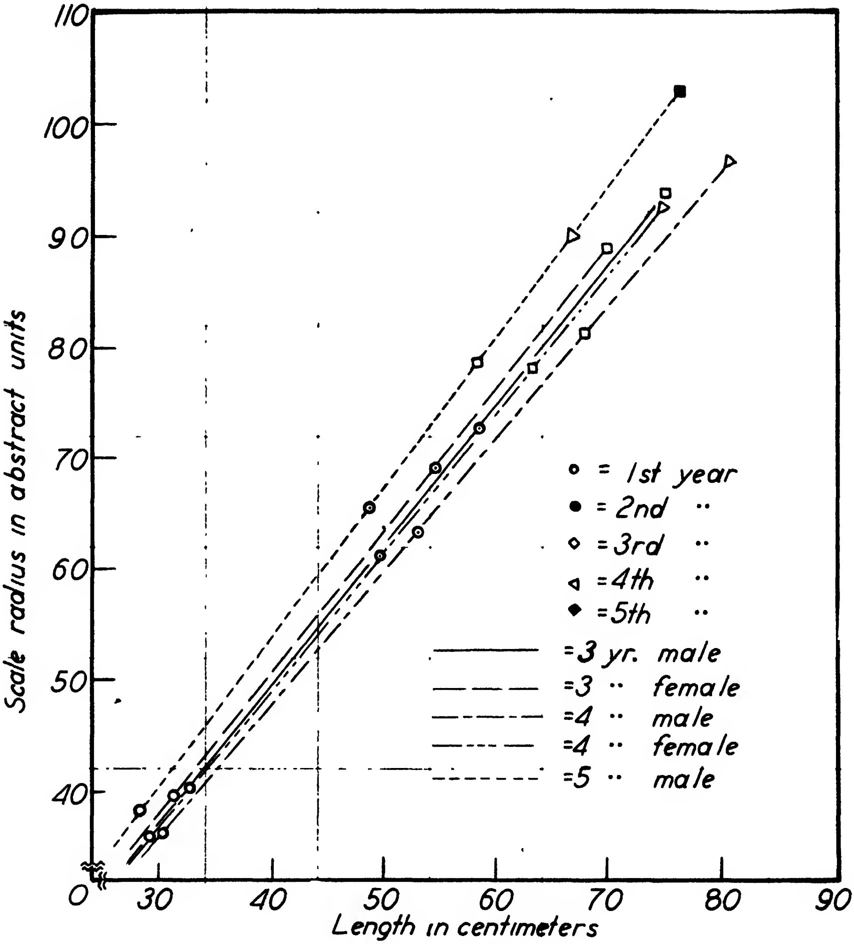

Fig. 7. Chums: relation of scale radius to fish length in Columbia River chums, grouped by sex and age.

123.70 and 10.05; for the three-year-old females, 126.75 and 10.36; for the four-year-old males, 119.85 and 9.65; and for the four-year-old females, 123.95 and 10.55. Comparison of the means of the distributions by a t test showed a significant difference to exist between three-year-old males and three-year-old females; three-year males and four-year males; three-year females and four-year females; and four-year males and four-year females. The fact that the R/L ratio is significantly higher for younger than for older fish is another indication of the disproportionate growth rates in scale and fish length in the older fish discussed above. The fact that the R/L ratio is significantly higher for the females than for the males may be interpreted as an indication of the relatively greater modification of

the sexually mature males. It has been pointed out by Gilbert (1922) that the male chums entering the Yukon River were more advanced sexually than the females: "It was the rule for the males to exhibit elongated jaws, provided with canine teeth, and to show the beginnings of the bright cross-bars that characterized the spawning male of this species." The greater modification of the males as sexual maturity develops is well known in all Pacific coast salmons. Relatively more elongation in the snout and jaws of males would naturally produce greater length measurements for them, thereby lowering the ratio of scale radius to fish length.

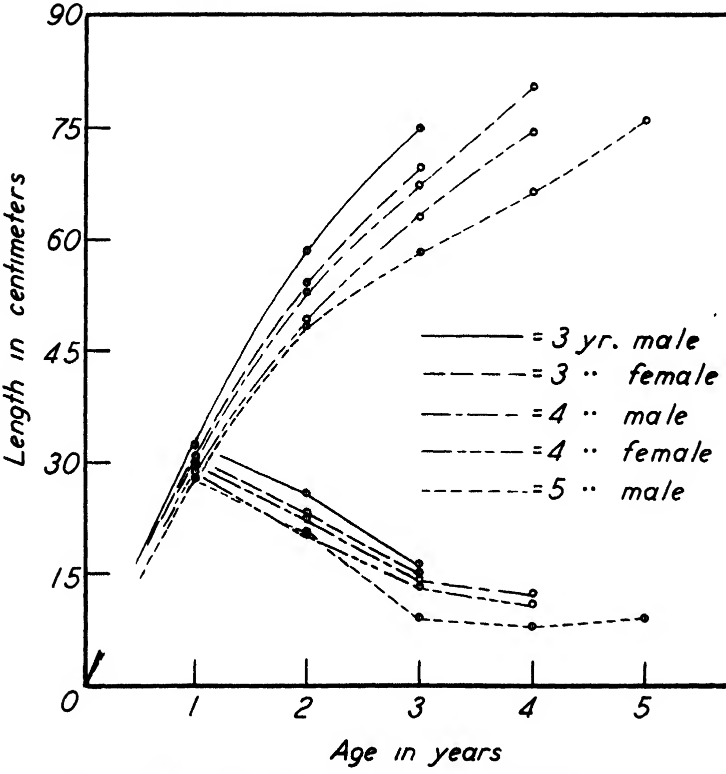

Fig. 8. Chums: growth curves and annual growth increments for all sex-age categories. The lower series of points for each year of age after the first are the increments.

Because these significant differences were found between the age classes and sexes, these groups were retained without further combination. The growth curves for all sex-age classes, and the annual growth increments, are shown in Figure 8.

LENGTH-WEIGHT RELATIONSHIP.—The relationship between length and weight may be expressed as $W=kL^x$, where "W" is weight, "k" is a constant, "L" is length, and "x" is a power closely approximating 3. This relationship has been demonstrated in *Leuresthes tenuis* by Clark (1925), in *Leucichthys artedi* by Van Oosten (1929), in *Perca flavescens* by Hile and Jobes (1941), and in many other fishes.

Since the length frequencies of the different age classes overlap to a large degree, and since the relationship of length and weight is approximately constant after the adult form has been attained, age classes were combined in the study of this relationship. Males and females were first examined separately. Measurements were available for 194 males and 181 females. Lengths were seriated in two-centimeter intervals, and the average weights determined for each length class. Since this is a power relationship, the logarithms of all measurements were used, and the regression line of log weight on log length ($\log W = a + b \times \log L$) was calculated by the

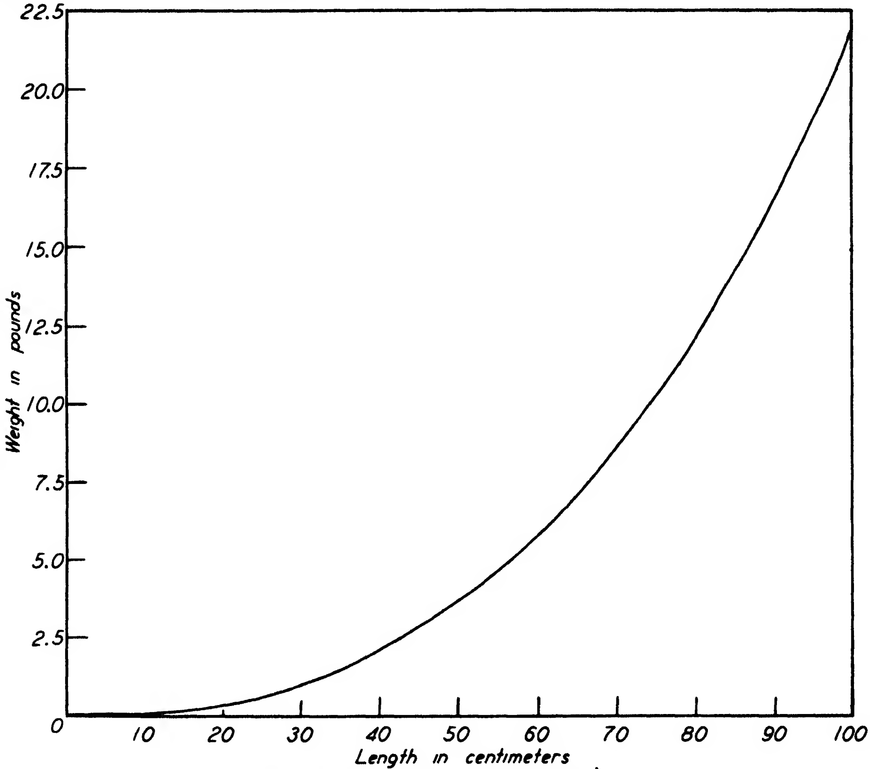

Fig. 9. Chums: length-weight curve based upon 375 Columbia River specimens, 60-92 centimeters in length.

method of least squares. For the males, the regression coefficient and its standard error are 2.50 and 0.0569, respectively; for the females, 2.82 and 0.0765. Comparison of the regression coefficients by a *t* test showed that the probability that the difference between them would be exceeded by chance is between 0.8 and 0.9. The relationship between length and weight apparently does not differ significantly between males and females, and the data were therefore combined. It should be noted that, in the calculations of the regression lines and the regression coefficients, the mean weight for each length was used, instead of the original paired variates. Since an estimate of the average weight for any given length was desired, this was permissible in the calculations of the regression lines. These regression coeffi-

cients are not exactly the same as though calculated from the original paired values, but are considered to be close enough to the true value for the purposes of the comparisons for which they have been used.

The length-weight curve for males and females combined is shown in Figure 9. The equation of this curve is $W=0.0001378 \times L^{2.6004}$

SEX RATIO.—The ratios of males to females for the different dates during the course of the collections are presented in Table 3. The ratio for the total sample is 1.10. If these samples have in fact been drawn from a population wherein males and females are equally represented, then the difference between the observed ratio and the theoretically expected ratio of 1.00 may be examined by the chi-square test. Chi-square and P values of 0.556 and 0.454, respectively, were obtained. It may be concluded, therefore, that the observed ratio of males to females for the total sample does not differ significantly from the theoretically expected ratio. However, certain variations in the sex ratios of the different samples will be noted, and these are discussed in the following section.

Table 3. Chums: sex ratio during the course of the run as sampled

Date	Three-year		Four-year		Five-year	Total			
	♂	♀	♂	♀	♂	♂♂	♀♀	N	♂♂/♀♀
10/13/14	4	..	4	1	1	9	1	10	9.00
10/22/14	28	11	10	10	1	39	21	60	1.86
10/23/14	48	31	10	15	...	58	46	104	1.26
10/30/14	24	43	20	14	...	44	57	101	0.77
10/31/14	46	51	31	17	2	79	68	147	1.16
11/16/14	7	20	1	4	...	8	24	32	0.33
11/17/14	14	16	4	3	...	18	19	37	0.94
11/20/14	15	7	1	4	...	16	11	27	1.45
Totals	186	179	81	68	4	271	247	518	1.10
% Totals	35.9	34.6	15.6	13.1	0.8				
♂♂/♀♀	1.04		1.19						

CHANGES DURING THE RUN.—As has been pointed out in the discussion of age, no consistent differences in the length frequencies of fish of the same age and sex for the different dates could be detected. Possible exceptions were noted in the case of the three-year-old males and the four-year-old females, but no changes in size were evident except such as might result from changes in the sex ratios, or in the relative abundance of the different age classes.

Table 4 shows the changes in the sex ratio over the course of the run, as sampled. The dates of collection were so grouped that it was convenient to combine them into periods, thereby removing irregularities due to small numbers. These periods are October 13 to 23, October 30 to 31, and November 16 to 20. Gilbert (1922) and others have observed the predominance of males in the early parts of salmon runs, with a reversal of the sex ratio later in the runs. This condition also obtains in the Columbia River chum salmon. The ratio of males to females in the mid-October group, 1.56, is significantly different from the expected ratio of 1.00 (chi-square test: $P<0.046$). The late October group is in almost perfect

concordance with theory. While the low value for the mid-November group, 0.78, does not show a significant difference statistically from 1.00 (chi-square: P=0.38), it still affords an indication of the continuation of the downward trend of the male-female ratio as the season advances.

Table 4. Chums: changes in the sex ratio during the course of the run as sampled

Date	♂♂	♀♀	N	% ♂♂	♂♂/♀♀
10/13-10/23	106	68	174	61.0	1.56
10/30-10/31	123	125	248	49.5	0.98
11/16-11/20	42	54	96	43.8	0.78

The predominance of males in the early part of the run is apparently related to the relatively greater abundance of older fish at that time, since males are more numerous than females in the older age classes. Table 5 shows that the five-year-old fish are not represented at all in the November collections; that the highest percentage of four-year-olds is in the late October series; while the highest percentage of three-year-olds is in the mid-November group.

Table 5. Chums: changes in the percentage of year classes during the course of the run as sampled

Date	3-year	4-year	5-year	N	% 3-year	% 4-year	% 5-year
10/13-10/23	122	50	2	174	70.1	28.7	1.2
10/30-10/31	164	82	2	248	66.1	33.1	0.8
11/16-11/20	79	17	...	96	82.3	17.7	...

RACIAL CHARACTERS OF THE COLUMBIA RIVER CHUMS.—A study of the racial characters of Columbia River chums should, ideally, be based upon large numbers of scale examinations, length and weight measurements, meristic counts, etc., taken from runs entering each tributary of the Columbia River in which chums spawn. It is quite probable that each of these tributaries may have its own race, whether distinguishable by anatomical or physiological characters, or both. The data used here, from the commercial catch on the Columbia River, are not divisible save by dates of collection. As shown previously, no consistent differences in lengths were demonstrable between dates, and the data were therefore combined. If races do exist in the Columbia River, it is impossible, on the basis of present knowledge, to distinguish them as mixed in the commercial catch. The observed changes in the sex ratios and in the percentages of year classes may, however, be an indication of the presence of such races. Thus, certain races may tend to mature in the fourth and fifth years and enter the run of any particular year earlier than those races that tend to reach maturity in their third and fourth years.

While independent races within the Columbia River system cannot be defined at present, it is believed that the data available may be used for comparison with similar data from other river systems. This belief is based upon two assumptions: that such races as may enter the Columbia River resemble each other more closely than they do races, say, from the Fraser or Yukon Rivers; and that spawning individuals are more likely to stray within the tributaries of the Columbia than they are to stray from the Columbia to rivers in British Columbia or Alaska.

Data from the following localities are available for comparison: Belling-

ham (Gilbert, 1913a); Admiralty Inlet (Rounsefell and Kelez, 1938); Chemainus, Nanaimo, and Qualicum (Fraser, 1920; 1921); Deep Water Bay, Granite Bay, Johnstone Strait, and Robsons Bight (Pritchard, 1932); and the Yukon River (Gilbert, 1922). The numbers, means, and standard deviations of the length-frequency distributions, grouped by sex and age, and listed from south to north, are given in Table 6. Rounsefell and Kelez (1938) and Pritchard (1932) give no length measurements, so only the numbers in each age class can be shown.

As stated above, the Columbia River material was measured to the nearest whole centimeter, with a tape over the body from the tip of the snout to the end of the middle caudal rays. Centimeters have been here converted to inches for comparative purposes. Gilbert's material from Bellingham and the Yukon River was apparently measured to the nearest half inch, in the same manner. Fraser's material from Chemainus, Nanaimo, and Qualicum was measured to the nearest half inch, exclusive of the caudal rays, and apparently not over the body. No data are available from which to derive a conversion factor for standardization to one or the other methods of length measurement. It must therefore be borne in mind that Fraser's measurements will be somewhat low by comparison with the other data. Gilbert (1922: 328) adds $7\frac{1}{2}$ per cent to Fraser's measurements to make them comparable, but gives no indication of the basis for this correction. It should also be noted that only the Columbia and Yukon data concern fish actually taken from rivers. However, it is reasonable to assume that fish taken in the Puget Sound—Gulf of Georgia area would have spawned in the streams close to the region of capture. The fact that these samples were not taken in the spawning streams may have resulted in an incorrect south-to-north listing as given in Table 6, since fish taken at Bellingham, for example, might conceivably have spawned north of the spawning grounds of fish taken at Chemainus. In considering the distance between the Columbia and Yukon Rivers, such discrepancies, if they exist, will be of minor importance. Other possible sources of variation may be mentioned: (1) some samples were taken from a small portion of the run, while others covered the main portion; (2) the samples taken in coastal waters, especially those taken over a considerable period of time, may have been taken from discrete local populations successively passing a given point; (3) the fish from different localities were taken by different types of gear (Columbia River fish were taken largely by gill nets, with a few trap fish; Gilbert's Bellingham material was apparently secured by purse seines; Rounsefell and Kelez' Admiralty Inlet samples were taken by purse seines; Fraser's material apparently was taken by purse seines; Pritchard's fish were taken by purse seines; and Gilbert's Yukon specimens apparently were caught in gill nets); and finally, (4) the data utilized cover a period of twenty-five years, and samples taken in any particular year may reflect varying oceanographic conditions, such as temperature, abundance and availability of food, etc. At present, little else can be done other than to acknowledge the existence of these possible sources of variation.

Consideration of Table 6 shows that the average length of each sex-age class consistently decreases from south to north. There are a few exceptions to this, largely in the small samples, but the trend is clearly evident. Mean lengths of each sex-age class are plotted against latitude in Figure 10. In relation to the distance between localities, the decrease in mean length from the Columbia River to the Gulf of Georgia is relatively greater than the decrease from the Gulf of Georgia to the Yukon River. However, latitude, as used here, is only an approximate expression of the sum of such environmental factors as abundance and availability of food, temperature, etc., with which rate of growth is actually correlated. Gilbert (1922) compared his Yukon and Bellingham material and Fraser's (1920) Gulf of Georgia material, and noted the northward decrease in size. In fact, he refers to

Table 6. Comparison of length (in inches) and age classes of Columbia River chums with material from other localities

(N is number, M is the mean, and SD is the standard deviation.)

Source		2-year ♂	2-year ♀	3-year ♂	3-year ♀	4-year ♂	4-year ♀	5-year ♂	5-year ♀	N
Columbia River, Oct. 13-Nov. 20, 1914	N	.....	.....	186	179	81	68	4	.....	518
	M			29.86	27.57	31.73	29.47	30.02		
	SD			1.60	1.21	2.17	1.53			
Gilbert (1913a), Bellingham, Aug. 2-3, 1910	N	1	.....	21	10	17	9	1	.....	59
	M	21.00		27.10	25.00	29.94	27.67	35.00		
	SD			2.17		2.86				
Rounsefell & Kelez (1938) Admiralty Inlet, Oct. 10—Nov. 11, 1935	N	....		334		463		78		875
	M									
	SD									
Fraser (1921), Chemainus, 1917	N	.....	.....	65	61	4	9	.....	.....	139
	M			24.99	24.31	28.50	27.89			
	SD			1.23	0.87					
Fraser (1921), Nanaimo, 1917	N	.....	.....	116	150	59	53	1	.....	379
	M			26.58	25.89	29.10	27.92	31.00		
	SD			1.10	1.03	0.91	0.71			
Fraser (1921), Qualicum, 1917	N	1	.....	94*	93*	232	83	3	.....	506
	M	21.00		26.6	25.9	29.12	27.96	30.83		
	SD					1.03	0.80			
Fraser (1920), Qualicum & Nanaimo, Sept. 5-Oct. 7, 1916	N	1		395	379	767	436	22		2000
	M			25.98	25.31	28.53	27.04			
	SD			1.13	0.96	1.31	1.15			
Pritchard (1932), Deep Water Bay, 1929	N	....		6		18		3		27
	M									
	SD									
Pritchard (1932), Granite Bay, Sept. 30-Oct. 8, 1930	N	....		186		319		7		512
	M									
	SD									
Pritchard (1932), Johnstone Strait, 1929	N	....		....		2		1		3
	M									
	SD									
Pritchard (1932), Robsons Bight, Sept. 9-19, 1930	N	....		81		264		4		349
	M									
	SD									
Gilbert (1922), Yukon River, June 15-July 31, 1920	N	.....	.....	8	7	164	141	86	42	448
	M			24.00	23.00	26.42	24.43	28.24	25.66	
	SD					1.19	1.02	1.36	1.08	

*Due to what is apparently a typographical error in Fraser's (1921) paper the means and standard deviations of these length frequencies cannot be calculated. These two means are Fraser's; all other means and standard deviations have been calculated for this paper.

Table 7. Chums: comparison of the percentage of age classes in samples from different localities

Source	Year	N	2-year		3-year		4-year		5-year		2-year	3-year	4-year	5-year	6-year
			♂	♀	♂	♀	♂	♀	♂	♀					
Columbia River....	1914	518	...	...	35.9	34.6	15.6	13.1	0.8	...	...	70.5	28.7	0.8	....
Bellingham Gilbert (1913a)...	1910	59	1.7	...	35.6	17.0	28.8	15.3	1.7	...	1.7	52.6	44.1	1.7*	....
Admiralty Inlet Rounsefell and Kelez (1938)....	1935	875	...	...	....	....	....	....	...	...	...	38.2	52.9	8.9	....
Chemainus Fraser (1921).....	1917	139	...	...	46.8	43.9	2.9	6.5	...	...	...	90.7	9.4	...	....
Nanaimo Fraser (1920).....	1916	700	...	0.1	19.9	26.7	32.6	19.9	0.9	...	0.1	46.6	52.4	0.9	....
Nanaimo Fraser (1921).....	1917	379	...	...	30.6	39.6	15.6	14.0	0.3	...	...	70.2	29.6	0.3	....
Qualicum Fraser (1920).....	1916	1300	...	...	19.7	14.8	41.5	22.9	1.0	0.2	...	34.5	64.3	1.2	....
Qualicum Fraser (1921).....	1917	506	0.2	...	18.6	18.4	45.9	16.4	0.6	...	0.2	37.0	62.3	0.6	....
Qualicum Pritchard (1943)..	1928	30	...	...	....	....	....	....	...	...	...	13.3	50.0	36.7	....
Deep Water Bay Pritchard (1932)..	1929	27	...	...	....	....	....	....	...	...	...	22.2	66.7	11.1	....
Granite Bay Pritchard (1932)..	1930	512	...	...	....	....	....	....	...	...	...	36.3	62.3	1.4	....
Johnstone Strait Pritchard (1943)..	1930	861	...	...	....	....	....	....	...	...	...	31.0	67.7	1.3	....

Johnstone Strait and Strait of Georgia Pritchard (1943)..	1941	143	...	...	....	....	....	....	...	...	...	0.7	28.0	56.0	15.3
Robsons Bight Pritchard (1932)..	1930	349	...	...	....	....	....	....	...	...	...	23.2	75.7	1.2	....
Nootka Pritchard (1943)..	1933	160	...	...	....	....	....	....	...	...	...	14.4	24.4	59.4	1.8
Nootka Pritchard (1943)..	1934	124	...	...	....	....	....	....	...	...	...	16.9	73.3	9.0	0.8
Nootka Pritchard (1943)..	1935	186	...	...	....	....	....	....	...	...	...	17.2	44.6	36.6	1.6
Nootka Pritchard (1943)..	1941	518	...	...	....	....	....	....	...	...	...	9.1	50.6	39.6	0.7
Barkley Sound Pritchard (1943)..	1941	179	...	...	....	....	....	....	...	...	...	3.9	41.4	49.7	5.0
Skidegate Inlet and Moresby Island Pritchard (1943)..	1940	373	...	...	....	....	....	....	...	...	...	0.5	24.1	72.4	3.0
Athlow Bay Pritchard (1943)..	1941	387	...	...	....	....	....	....	...	...	...	....	20.7	67.2	11.9
Skidegate Inlet and Inskip Channel Pritchard (1943)..	1942	213	...	...	....	....	....	....	...	...	...	....	4.2	75.5	19.8
Yukon River Gilbert (1922)....	1920	448	...	...	1.8	1.6	36.6	31.5	19.2	9.4	...	3.4	68.1	28.6	....

*Percentages in this and other tables do not always total exactly 100.0 due to the practice of carrying only one decimal.

the Yukon chums as the "northern race," but does not go into the problem of whether diminution of length, retarded age at maturity, etc., are heritable characteristics, or merely the limitations imposed by the environment upon each individual fish, or a combination of the two.

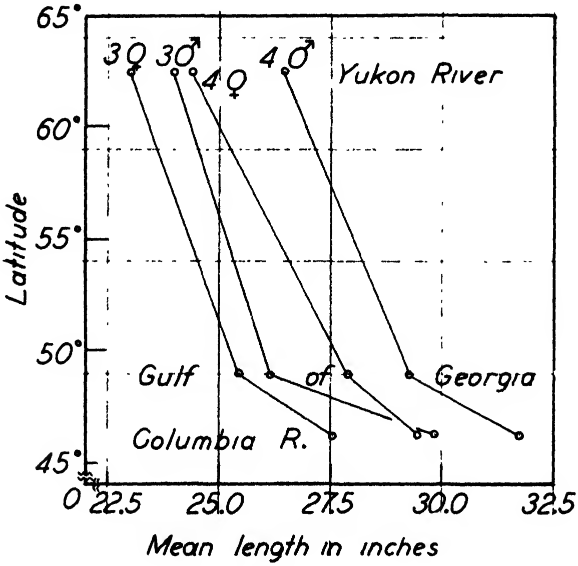

Fig. 10. Chums: relation of mean lengths of sex-age categories to the latitude of the localities. Gulf of Georgia data are the weighted averages of Bellingham (59 specimens), Chemainus (139), and Nanaimo (379) samples.

The percentages of age classes are given in Table 7. In addition to the previous comparative data, percentages as given by Pritchard (1943) are included. His data represent fish from Qualicum, Johnstone Strait, and the Strait of Georgia, the west coast of Vancouver Island (Nootka and Barkley Sound), and the Queen Charlotte Islands (Skidegate Inlet, Moresby Island, Athlow Bay, and Inskip Channel). All fish involved were "taken by commercial gear."

Apparently, two-year-old chums are a rarity in the commercial catches. Omitting the smaller samples (those having less than sixty specimens) from consideration, examination of Table 7 reveals that there is a generalized south-to-north trend in the relative abundance of the different age classes; the southern localities tend to have a larger percentage of younger fishes, and the northern localities to have a larger percentage of older fishes. Pritchard (1943) has pointed this out in his British Columbia material. Not included in Table 7 are two seven-year-old chums, determined "with reservations" by Pritchard. He also records six-year-old chums, which, as far as is known, have not been observed previously. It should be noted that his age determinations include a greater percentage of older fish than have been obtained previously from any locality.

Especially interesting, as pointed out by Fraser (1921) and by Pritchard (1943), are the differences in the relative abundance of age classes in samples taken at the same locality in successive years. Since these samples were not taken

in rivers, the question arises as to whether or not they are comparable as successive annual samples from a single population. They are recorded by year only, so it is impossible to obtain any information by the comparison of the monthly dates of successive collections. If these samples are from the same populations and were taken from comparable parts of the runs, the fluctuations must be reflections of the biotic conditions in the sea. Davidson (1940) has pointed out that, with the exception of the pink salmon, which always mature in their second year, the average length of a year class of the Pacific salmons remains fairly constant from year to year, and, while the percentage of age classes is fairly constant, it may at times fluctuate as a result of environmental factors.

Judging from the comparison of lengths, it is to be expected that weights are also reduced from south to north, if the weight-length relationships remain fairly constant. Data from all collections are not included, but the Yukon River data are given in Table 8, as an example. These data may be compared with the Columbia River chums' length-weight curve (Fig. 8).

Table 8. Average lengths and weights of Yukon River chums given for all sex-age groups*

	3-year		4-year		5-year	
	♂	♀	♂	♀	♂	♀
Average weight in pounds	6.5	5.6	8.3	6.5	10.5	7.7
Average length in inches	24.00	23.00	26.42	24.43	28.24	25.66

*The data are taken from Gilbert (1922).

Data on growth are available from Fraser (1921) for comparison with similar data on the Columbia River chums. These are presented in Table 9, as annual increments in terms of percentage of fish length at maturity. Here again, it must be remembered that, due to the difference in method, Fraser's fish length measurements will be low. Also, due to Fraser's method of correcting for initial growth, the calculated lengths for the Gulf of Georgia material will be relatively high in comparison with those of Columbia River chums. Since only four fish are represented, the data for the five-year-old Columbia River chums are not reliable. In chums from all localities, it is evident that the amount of growth in any particular year of their life is greater in the younger fish than in the older fish. The major differences in rate of growth between Columbia River and British Columbia chums are in the first and last years of life. Columbia River fish seemingly grow more in the last year than do those from British Columbia. This may be due to the fact that the British Columbia specimens were taken in coastal waters, and probably from a relatively earlier part of the run, than were those from the Columbia River; the latter were all taken after the runs had entered the river, and thus enjoyed a somewhat longer period of growth in their last year. If this is in fact the case, then it may be that there is really no difference in the first year's growth; that is to say, if the British Columbia chums had been taken at a later date in their spawning streams, they would have been larger, the percentage of growth in the last year would have been increased, and the percentage of growth in preceding years correspondingly reduced.

The sex ratios shown in Table 10 are in close agreement with the expected ratio of 1.00, with three exceptions: the one sample from Bellingham, and the two from Qualicum. In each of these samples, the ratio of males to females is high,

Table 9. Chums: comparison of growth, expressed as annual increments in percentage of length at maturity, in samples from different localities

Source	Year	2-year ♂	2-year ♀	3-year ♂	3-year ♀	4-year ♂	4-year ♀	5-year ♂	5-year ♀
Columbia River, 1914.	1	....	....	43.6	44.5	37.7	38.8	37.0	....
	2	....	....	34.6	33.2	28.1	27.2	26.9	....
	3			21.8	22.3	18.4	18.3	12.8	....
	4					15.8	15.7	10.8	....
	5							12.5	....
Chemainus, 1917......	1	....		48.1		42.5		....	
	2	....		32.8		28.1		....	
	3			19.1		17.8		....	
	4					11.4		....	
	5							....	
Nanaimo, 1917........	1	....		46.4		40.2		31.3	
	2	....		33.3		28.7		24.2	
	3			21.5		18.5		18.7	
	4					12.6		15.0	
	5							10.0	
Qualicum, 1917.......	1	57.1		45.4		40.8		35.0	
	2	42.9		33.6		28.2		25.7	
	3			21.0		18.5		17.9	
	4					12.6		13.3	
	5							8.4	

and the difference from the hypothetical 1:1 ratio is statistically significant. No satisfactory explanation of the predominance of males in these collections is available. As stated previously, no monthly dates were given by Fraser, but it seems quite possible that the ratio of males to females would not have differed significantly from theory had the entire run been proportionately represented in the sampling. In all samples, except that from Chemainus, the males are in excess in the four- and five-year classes. Since these older males are relatively more abundant in the early portion of the runs, it may be that the Qualicum collections oversampled the early part of the run.

Table 10. Chums: comparison of sex ratios in samples from different localities

Source	N	2-year ♂♂/♀♀	3-year ♂♂/♀♀	4-year ♂♂/♀♀	5-year ♂♂/♀♀	Total ♂♂/♀♀
Columbia River...........	518	.....	1.04	1.19	4/0	1.10
Bellingham..............	59	1/0	2.10	1.89	1/0	2.11
Chemainus................	139	.....	1.07	0.44	.....	0.99
Nanaimo, 1916...........	700	0/1	0.74	1.64	6/0	1.14
Nanaimo, 1917...........	379	.....	0.77	1.11	1/0	0.87
Qualicum, 1916..........	1300	.....	1.33	1.82	4.33	1.64
Qualicum, 1917..........	506	1/0	1.01	2.80	3/0	1.88
Yukon River..............	448	.....	1.14	1.16	2.05	1.36

The time of the runs also changes with the latitude of the streams. In the Columbia River the major portion of the run occurs in October and November; in the Gulf of Georgia region it is in September and October; while the Yukon run is in the latter part of June and in July.

It would seem that the differences demonstrated above are, in all probability, expressions of genetic differences, due to the selective effect of varying environmental conditions. Data, other than that already presented, are not available for North American chums, but Katayama (1935) has apparently been able to distinguish races of chums near Japan, on the basis of certain meristic counts. Kubo (1938) attempted to separate races on the basis of characteristics that are merely expressions of the degree of external modification accompanying sexual maturity and the spawning runs.

Knowledge of the differences between the salmon races of different river systems, while of biological interest, will probably be of little use in a fisheries management program, unless it should later prove possible to follow the various races of salmon during their oceanic life, and to connect them with a parent stream on the basis of these known characteristics. However, knowledge of the racial characters of the races of various tributaries of a single river system may be of extreme importance; for if the races of the various tributaries are sufficiently distinct, it would be possible to determine by sampling which particular races were passing through the commercial fishery at any given time. The fishing intensity could then be regulated, as the various races pass through the fishery, in accordance with the escapement necessary to maintain the runs of the tributaries. The differences between the races of the tributaries of the Columbia River will probably prove to be of the same nature as those demonstrated above between river systems.

PINKS

As stated above, the pink salmon does not enter the commercial catch of the Columbia River; only occasional specimens are seen, and these are probably strays from other streams. In the samples at hand, there are data on six pinks: one male, and five females. The male was secured on July 28, two females on July 28, two on July 30, and one on August 18, 1914. There is nothing distinctive about the scales, which follow the general pattern of pink salmon scales in more northern waters, where this species has its center of distribution. All scales show evidence of two years of growth in the ocean and none in fresh water. Scales of male and fe-

Table 11. Pinks: data on individual specimens

Sex	Length in cm.	Weight in pounds	Total scale radius in mm.	Scale radius at end of first year in mm.	Estimated length at end of first year in cm.
M	68	7.5	1.57	0.81	35
F	59	5.0	1.83	1.04	34
F	54	...	1.73	0.99	31
F	53	4.0	1.43	0.87	32
F	50	3.5	1.57	0.89	28
F	47	3.0	1.83	1.00	26

male pinks are shown in Figures 11 and 12, respectively. The data relating to the individual specimens are given in Table 11. Little more can be said about such a small sample, and the data are presented here chiefly as a matter of record.

Fig. 11 (left). Pink: scale from a two-year-old male, 68 centimeters long, taken in the lower Columbia River on July 28, 1914.

Fig. 12 (right). Pink: scale from a two-year-old female, 53 centimeters long, taken in the lower Columbia River on July 30, 1914.

SILVERS

Silver salmon have received relatively less attention in biological investigations than have the Chinook and blueback salmons, but are better known than the chum salmon. In addition to the references cited above for the chums, which also include information on the silvers, further contributions have been made by Fraser (1917), by Snyder (1931) on the run in the Klamath River, and by Pritchard (1936; 1940) on the accessment of age. Little has been known of the details of the biology of the Columbia River silver salmon.

The samples studied were taken at random from the commercial catch on August 22, September 12, 16, October 12, 13, 21, 22, 28, 29, and November 12, 16, and 20, 1914. During this period, approximately 95 per cent of the run passes through the lower part of the river (Rich, 1942: 109). All fish were taken in gill nets in the lower Columbia River and landed at Ilwaco, Washington. The assumptions made for the chum samples hold here; namely, that the samples are representative of that part of the commercial catch from which they were drawn, but are not truly representative of the total run, inasmuch as there will be a tendency for the smaller and larger sizes to be inadequately represented, because of the selective action of the gill nets by which the fish were taken.

AGE AND LENGTH.—Ages were determined from the scales by the accepted methods of interpretation. All scales were examined twice, with a compound microscope, and without reference to length or weight measurements, or to previous examinations. Of the total number of scales examined (885), disagreements and doubtful age determinations amounted to 17.3 per cent. As in the case of the chums, doubtful determinations and disagreements between successive readings were reexamined and final decisions made; as a result, changes amounting to 12.1 per cent of the total were made.

Fig. 13 (left). Silver: scale from a two-year-old male that had gone to sea in its second year (2_2), 44 centimeters long, taken in the lower Columbia River on November 12, 1914.

Fig. 14 (right). Silver: scale from a three-year-old male that had gone to sea in its third year (3_3), 46 centimeters long, taken in the lower Columbia River on October 22, 1914.

Fig. 15. Silver: scale from a three-year-old male that had gone to sea in its second year (3_2), 74 centimeters long, taken in the lower Columbia River on August 22, 1914.

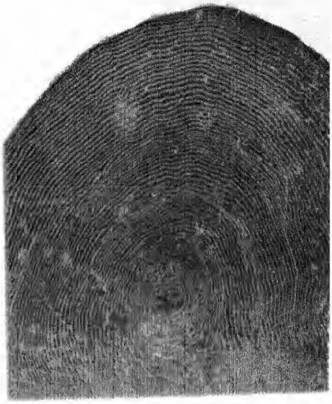

Fig. 16. Silver: scale from a three-year-old female that had gone to sea in its second year (3_2), 58 centimeters long, taken in the lower Columbia River on November 16, 1914.

Fig. 17. Silver: scale from a four-year-old male that had gone to sea in its third year (4_3), 79 centimeters long, taken in the lower Columbia River on October 22, 1914.

Fig. 18. Silver: scale from a four-year-old female that had gone to sea in its third year (4_3), 74 centimeters long, taken in the lower Columbia River on November 16, 1914.

Silver salmon scales are relatively more difficult to interpret than chum scales, since the silvers may leave fresh water in their second or third years, and may return from the ocean in their second, third, or fourth years. This greater complexity naturally introduces a greater amount of variation due to personal interpretation. It must be stated, therefore, that all age determinations, particularly in the four-year-old group, are tentatively given until such time as they may be verified by marking experiments. However, the results obtained do not differ materially from results obtained by workers in other localities. In recording age categories, the convenient system used by Gilbert and Rich (1927) was adopted. This consists of two figures, of which the second is written as a subscript to the first. The first figure designates the year of life in which the fish was captured, which is usually the age at maturity. The subscript shows the year of life in which the fish made its migration from fresh water to the sea. Thus fish that had gone to sea in the spring of their second year and returned toward the end of their third year are designated by the symbol 3_2—the most common category of Columbia River silver salmon. Other categories in the collections studied are 2_2, 3_3, and 4_3. Representative scales of all sex-age categories are shown in Figures 13 to 18.

Pritchard (1936; 1940), in addition to the above age categories, has reported silvers from British Columbia that left fresh water in their first year (as fry), and returned either in their second (2_1), third (3_1), or fourth (4_1) year; and fish that left fresh water in their second year, and returned in their fourth year (4_2). These will be discussed below in greater detail.

Examination of Figures 13 to 18 will reveal some of the main difficulties encountered in interpreting these scales. The circuli representing the fresh water and estuarine growth in the early part of the year in which the fish went to sea may at times be confused with a full year's life in fresh water. A similar difficulty was encountered by Rich (1920) in his study of Columbia River Chinook salmon. The silver salmon scales, particularly those which have been interpreted as representing fish which matured in their third year and went to sea in their second year (3_2), had a tendency, in many instances, to have a split band of winter circuli at the end of the second year, or an accessory check immediately preceding the band of winter rings that forms the second annulus. Generally, the true annulus was easy to recognize, due to its relative position, prominence, and its union with the accessory check at the dorsal and ventral margins of the scale. There were various degrees of separation of the true annulus and the accessory check; and, in a very few instances, the accessory check was more prominent than and so widely separated from the annulus that it was impossible to decide whether the fish belonged in the 3_2 or the 4_2 category. It is believed that these fish were, in reality, 3_2, but since no corroborative evidence from marked fish is available, they were omitted from further consideration. The number of scales omitted, due to this indecision as to age, or to regenerated "nuclei," broken margins, etc., amounted to only 1.5 per cent of the total number examined.

The length-frequency distributions according to sex and age are given in Table 12. It will be noted that the sex-age groups seem to be fairly distinct; that males tend to be larger than females, and that older fish tend to be larger than younger fish. An apparent exception to the last statement is shown by the length frequencies of the four-year-old fish (4_3), which are slightly smaller than the fish of the 3_2 group, from which they differ only in having spent one more year in fresh water before migrating to sea. If the ages have been determined correctly, the four-year-old fish apparently have a slower rate of growth than do the three-year-olds (3_2). The 3_2 fish are the predominant year class, comprising 83.9 per cent of the total sample. The 4_3 fish make up 9.7 per cent, the 2_2 fish 6.1 per cent, and the 3_3 fish amount to only 0.3 per cent of the total. The single 2_2 fe-

Table 12. Length-frequency distributions of 885 silver salmon from the Columbia River, 1914, grouped by sex and age

Length in cm.	2_2 ♂	2_2 ♀	3_3 ♂	Length in cm.	3_2 ♂	3_2 ♀	4_3 ♂	4_3 ♀
34	1			55	1			
5	1			6	1			
6	2			7				
7	2			8	1	2		1
8	1		2	9	2			
9	8			60	1			
40	7			1	2	1		
1	3			2	1	1		
2	5			3	3			
3	7			4	10	1		
4	6			5	4	6		1
5	1			6	9	8	1	2
6	1		1	7	6	4	5	
7	5	1(?)		8	10	3		1
8				9	11	19	1	2
9	1			70	7	18	1	4
50				1	10	14	4	2
1				2	20	22	2	3
2				3	12	29	1	3
3				4	27	35	3	6
4				5	13	34	1	3
5				6	14	29	1	4
6	1			7	20	29	2	4
				8	12	30		4
				9	20	34	1	3
				80	19	25	1	5
				1	16	12	2	1
				2	21	12	1	1
				3	15	6	1	
				4	15	2	4	
				5	13	3	2	
				6	8			
				7	6			
				8	4			
				9	8		1	
				90	4			
				1	4			
				2	1			
				3				
				4				
				5	1			
Means.............	41.81				76.70	75.04	75.69	74.22
Standard deviations	3.87				7.30	4.56	6.52	4.76
Number............	53		3		731		85	
Per cent of total number.....	6.1		0.3		83.9		9.7	

male is included with reservations. No female grilse have been reported previously, and it is probable that this individual was a male, and that an error has been made somewhere in the recording or transcription of data.

GROWTH.—The silver salmon scales were measured in the same manner as the chum scales. However, instead of projecting the scale images, the relative distances were measured directly by means of a measuring device consisting of an Ames gauge attached to a mechanical stage under a compound microscope. This permitted direct measurement of scale radii in units of 0.01 millimeter.

As before, careful attention was paid to the possibility of absorption of the scale margins. Little of this was detected, but apparently these scales were more fragile than the chum scales, and had suffered more marginal destruction in handling. However, in most cases where the margin was injured, only small fragments were actually missing, so that it was possible to determine the true periphery of the scale. It was necessary to omit 52 scales from the growth study, due largely to the fact that the scales were mounted in such a way that it was impossible to measure the radii in the anterior quadrant, even though age determinations were readily made. New mounts might have been made, except for lack of time.

The calculation of length at earlier ages was done, as in the chums, by assuming the proportion $R_t:L_t = R_x:L_x$ to be true, and the calculated lengths were read directly from a ten-inch slide rule. The common means of scale radius and fish length were determined for each year in each sex-age category, and are presented in Table 13. The trend for the ratio of scale radius to fish length to be greater for females than for males, and greater for younger than for older fish—so clear in the chum salmon—is greatly reduced or absent here. Lack of time prevented further examination of these data to determine if the small differences present were significant. However, since these differences are small, whether statistically significant or not, it was decided to combine the data by age classes for this study.

Table 13. Silvers: means of scale radius (R) in 0.01 millimeter and of fish length (L) in centimeters at each age for each sex-age category*

Age	2_2 ♂ N = 50		3_3 ♂ N = 3		3_2 ♂ N = 325		3_2 ♀ N = 379		4_3 ♂ N = 34		4_3 ♀ N = 49	
	R	L	R	L	R	L	R	L	R	L	R	L
End 1_1	37.60	7.74	30.67	6.33	35.35	7.20	34.35	6.92	27.20	5.32	25.35	5.06
End 2_2	198.50	41.72	49.33	9.67	241.30	49.51	237.10	48.15	49.95	9.91	48.40	9.67
End 3_2			.....	....	374.80	76.79	370.20	75.06	.....	....	.....	....
End 3_3			206.67	40.67					238.85	48.24	240.75	48.18
End 4_3									374.90	75.79	371.90	74.25

*The terminal ("oldest") figures in each column represent actual size of scale and fish at time of capture sometime during the last year of growth, and are not necessarily, if ever, the end of the last year's growth.

The common means of scale radius and fish length, and the annual growth increments for each age class, are given in Table 14, and the lines relating these common means are shown in Figure 19. Growth curves for each age class are presented in Figure 20.

LENGTH-WEIGHT RELATIONSHIP.—Length and weight measurements were available for 285 males and 320 females. The regression of weight on length was determined separately for males and females, as for the chums. Comparison of the regression coefficients by a *t* test showed that the length-weight relationship did not differ

Table 14. Silvers: means of scale radius (R) in 0.01 millimeter, of fish length (L) in centimeters and the calculated annual growth increments (I) at each age for each age class

Age	2_2			3_3			3_2			4_3		
	R	L	I	R	L	I	R	L	I	R	L	I
End 1_1	37.60	7.74	7.74	30.67	6.33	6.33	34.85	7.05	7.05	26.10	5.17	5.17
End 2_2	198.50	41.72	33.98	49.33	9.67	3.34	239.10	48.80	41.75	48.90	9.77	4.60
End 3_2				.....	....	....	372.40	75.97	27.17	.....	....	....
End 3_3				206.67	40.67	31.00				239.95	48.21	38.44
End 4_3										373.10	74.88	26.67

significantly (P=approximately 0.3) between males and females, and the data were therefore combined. This relationship for the combined data is expressed by the formula $W=0.0000373 \times L^{2.8945}$, where "W" is weight and "L" is length, and is shown graphically in Figure 21.

SEX RATIO.—The sex ratios for the collections are given in Table 15. The ratio of males to females for the combined collections is 1.02, which is in almost perfect agreement with the theoretically expected ratio of 1.00. Females are in excess of males in the older age classes, but this excess is offset by the presence of grilse, which are almost invariably males. Changes in the sex ratio over the course of the collections will be considered in the following section.

Table 15. Silvers: sex ratio during the course of the run as sampled

Date	2_2		3_3	3_2		4_3		Total			
	♂	♀	♂	♂	♀	♂	♀	♂♂	♀♀	N	♂♂/♀♀
8/22.......	1	....	...	56	38	10	9	67	47	114	1.43
9/12.......	4	....	...	....	....	...	...	4	...	4	4/0
9/16.......	5	1(?)	...	....	....	...	...	5	1	6	5.00
10/12......	2	....	...	19	19	1	1	22	20	42	1.10
10/13......	19	....	2	16	18	1	1	38	19	57	2.00
10/21......	...	....	...	18	23	1	2	19	25	44	0.76
10/22......	3	....	1	29	31	2	4	35	35	70	1.00
10/28......	10	....	...	29	46	2	4	41	50	91	0.82
10/29......	1	....	...	78	60	7	9	86	69	155	1.25
11/12......	1	....	...	31	49	4	8	36	57	93	0.63
11/16......	2	....	...	26	26	3	3	31	29	60	1.07
11/20......	3	....	...	50	70	4	9	57	79	136	0.72
Totals.....	52	1(?)	3	352	379	35	50	441	431	872	1.02
% Total....	6.0	0.1	0.3	40.3	43.5	4.0	5.7				
♂♂/♀♀......	52.00		3/0	0.93		0.70					

CHANGES DURING THE RUN.—Previous workers, including Gilbert (1913b), Fraser (1917), and Rounsefell and Kelez (1938), have noted the remarkable growth of silver salmon in the summer immediately preceding sexual maturity. This condition was observed in the data studied, particularly in the 3_2 fish.

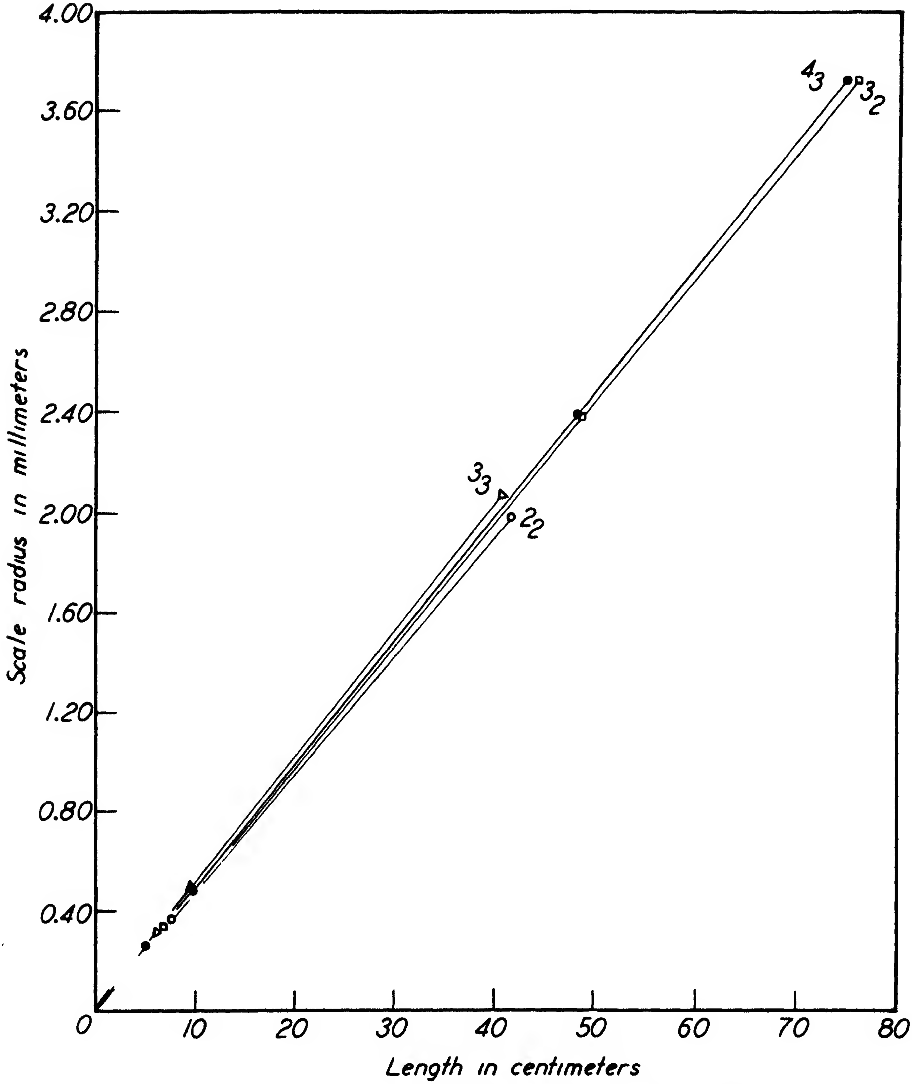

Fig. 19. Silvers: relation of scale radius to fish length in Columbia River silvers, grouped by age classes.

Figure 22 shows the mean lengths of the 3_2 males and females for each collection. It is apparent that the collection made on August 22, comprising 67 males and 47 females, is composed of distinctly smaller fish than those of the October-November collections—a difference that is probably associated with the fact that the fish taken later in the season had spent approximately two months longer in

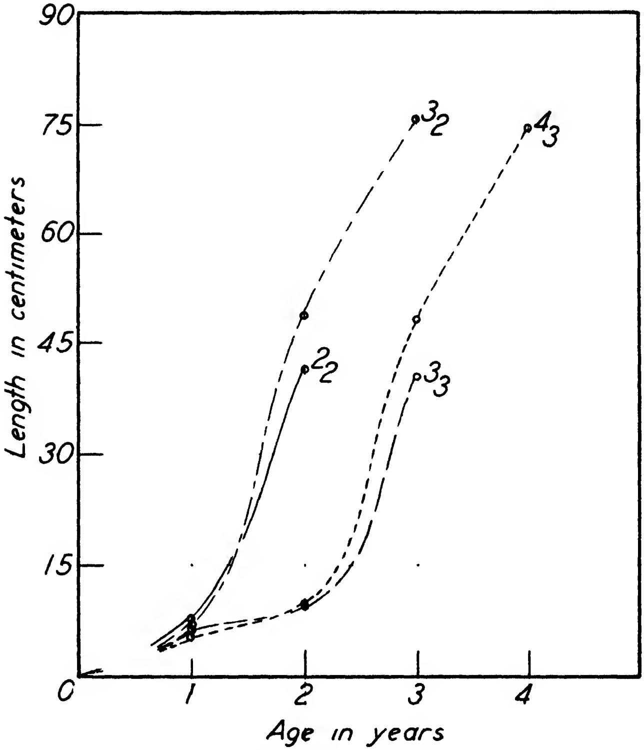

Fig. 20. Silvers: growth curves for all age categories.

the sea. Omitting the August collection, the data for the others were further studied, by means of the analysis of variance, to determine whether there were any other changes in length associated with time during October and November. In the case of the males, the differences between samples were slightly above the 1 per cent level of significance; for the females, the differences were slightly below. The 2_2, 3_3, and 4_3 fish, when segregated by dates of collection, did not lend themselves well to analysis, due to the small numbers in each collection. However, by inspection it was seen that there was a general tendency within these age groups for longer fish to be taken on the later dates. The mean lengths of the 3_2 males and females for each collection are shown in Figure 22, and from this it appears that there is probably a slight increase in the length of the males during the period covered by the October-November collections. No evidence of such a trend is apparent in the case of the females, and it therefore seems probable that the slight increase in the males is due to the development of the elongated snout that is characteristic of the breeding males.

The sex ratios during the course of the run, as sampled, are presented in Table 16. To remove irregularities due to small numbers, and to facilitate comparison with respect to time, the collections were combined by months: August (Aug. 22), September (Sept. 12 and 16), October (Oct. 12, 13, 21, 22, 28, and 29), and

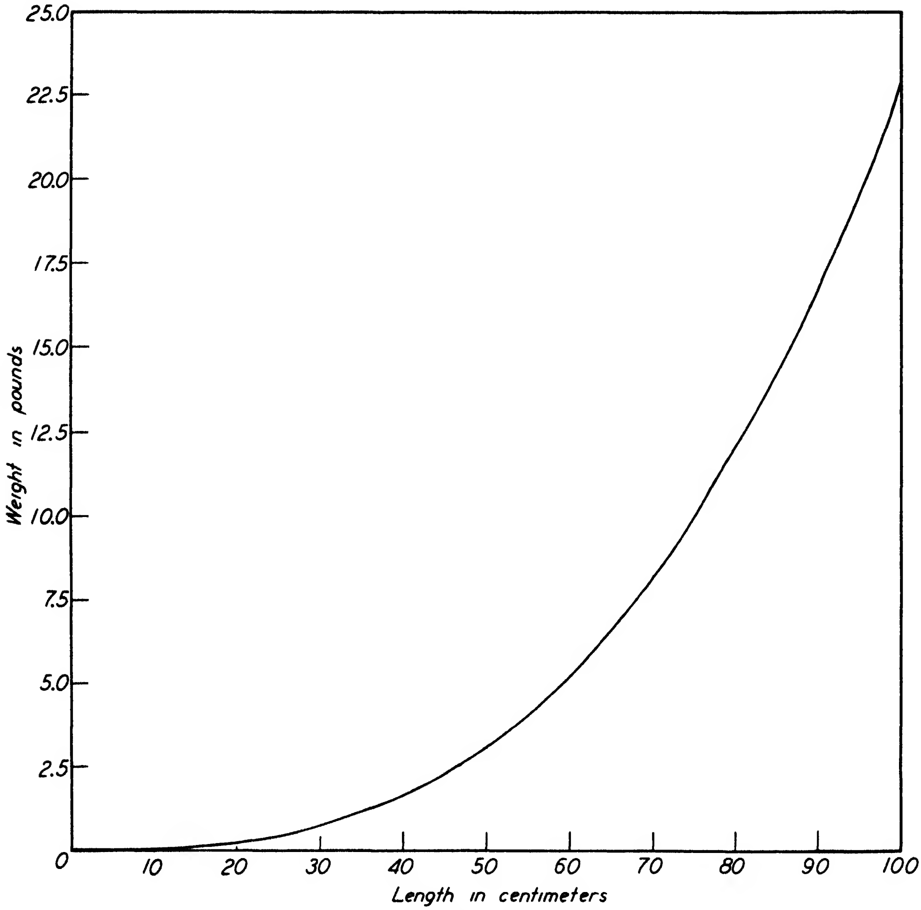

Fig. 21. Silvers: length-weight curve based on 605 Columbia River specimens, 37-92 centimeters in length.

Table 16. Silvers: changes in the sex ratio during the course of the run as sampled

Date	♂♂	♀♀	N	% ♂	♂♂/♀♀
8/22............	67	47	114	58.8	1.43
9/12-9/16........	9	1(?)	10	90.0	9.00
10/12-10/29......	241	218	459	52.5	1.11
11/12-11/20......	124	165	289	42.9	0.75

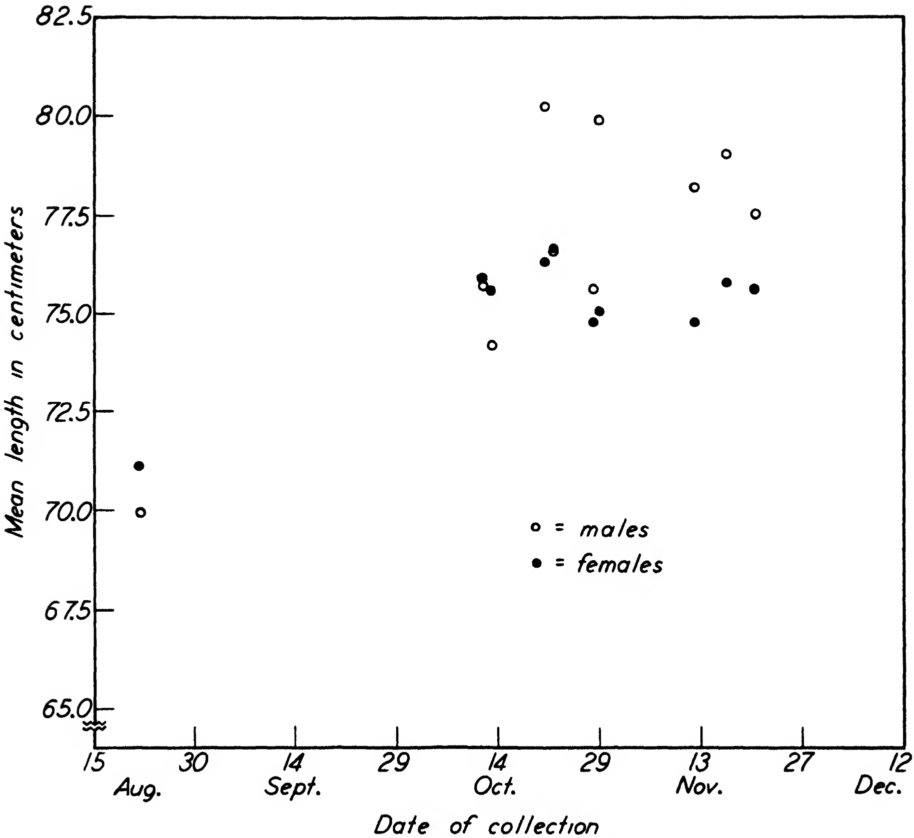

Fig. 22. Silvers: mean lengths of 3_2 males and females for each collection.

November (Nov. 12, 16, and 20). The September collections may be omitted from consideration, because they were small and probably selected, since all specimens were grilse of the 2_2 age group. As with the chum salmon, males were in excess in the early part of the run, and females in the latter part of the run. The probabilities that these ratios would be equaled or exceeded by chance (that is, differ by chance from 1.00) are: for August, $P<0.2>0.1$; for October, $P<0.5>0.3$; and for November, $P<0.1>0.05$. None of these differences are significant when judged by commonly accepted statistical standards, but the trend from more males in the early part of the run to more females in the latter part of the run is clearly shown.

The percentages of age classes are given in Table 17. The collections have again been grouped by months. Although the relationship between changes in the percentage of age classes and the sex ratio probably is not as simple in the silvers as in the chums, certain tendencies may be noted. The September collections again are omitted from consideration, as are 3_3 fish, since only three were taken. The 2_2 fish, which may be considered to be all males, increase in relative abundance from August to October, but decrease in November; the lowest percentage is

in August. The 3_2 fish, with females in excess of males, increase slightly in relative numbers from August to November. The 4_3 fish, with females again in excess, are relatively less abundant in October and November than in August, but the lowest percentage is in October. The apparent trend is for the relative abundance of 2_2 and 3_2 fish to increase with time, and for that of 4_3 fish to decrease with time. These are similar to the conditions observed in the chum salmon run. It should be stated, however, that the percentage of 2_2 fish probably is not exceedingly reliable, insofar as the total run is concerned. Due to their relatively small size, and the selective action of the gill nets, they may be inadequately represented in the commercial catch; but the representation on different dates should be proportional to the true abundance.

Table 17. Silvers: changes in the percentage of age classes during the course of the run as sampled

Date	2_2	3_3	3_2	4_3	N	% 2_2	% 3_3	% 3_2	% 4_3
8/22.........	1	..	94	19	114	0.9	....	82.5	16.7
9/12-9/16....	10	..	...	..	10	100.0	....	....	....
10/12-10/29..	35	3	386	35	459	7.6	0.7	84.1	7.6
11/12-11/20..	6	..	252	31	289	2.1	....	87.2	10.7

RACIAL CHARACTERS OF THE COLUMBIA RIVER SILVERS.—As stated previously, a study of the racial characters of the salmons entering the Columbia River should be based upon consideration of the populations entering each tributary of the Columbia in which the species in question spawns. Such data are not available, so that it is not possible at present to distinguish races as mixed in the commercial catch. However, comparison of the data at hand with similar data from other localities, while it may or may not provide a basis for the separation of the various populations during their oceanic life, will probably provide a qualitative estimate of the differences that later may be demonstrated between populations of a single river system, and also provide information of biological interest.

Data from the following localities are available for comparison: Puget Sound (Gilbert, 1913a); Strait of Georgia and Neah Bay (Fraser, 1917; 1920); Quathiaski cannery (Cape Mudge to Heriot Bay), Lasqueti cannery (Lasqueti and Texada Islands), Fraser River (Nanaimo cannery, but "definitely localized on the way to the spawning grounds"), and Nanaimo cannery (Lasqueti Islands, Qualicum, Northwest Bay, Winchelsea Islands, to Gabriola Pass and Cowichan Gap) (Fraser, 1921); British Columbia ("the north coast of the Queen Charlotte Islands in the north to the Strait of Georgia in the south") (Pritchard, 1936; 1940); and the Yukon River (Gilbert, 1922). The sources of variation in these data are of the same nature as those described for the chums.

The numbers, means, and standard deviations of the length-frequency distributions, grouped by sex and age, and listed from south to north, are shown in Table 18. As previously explained, Fraser's measurements are somewhat low in comparison with the others, and Gilbert's samples are very small, but the reduction in mean length of each group, from south to north, is very evident. It is interesting to note that the variation in length is, in every instance, greater for males than for females, as in the chum salmon. This may again be due to the variation in the degree of modification of the secondary sexual characters of the male at maturity.

The percentages of age classes, as shown in Table 19, do not include 7 spec-

Table 18. Comparison of length (in inches) and age classes of Columbia River silvers with material from other localities
(N is number, M is the mean, and SD is the standard deviation.)

Source		2_2		3_2		3_3		4_3		5_4	N
		♂	♀	♂	♀	♂	♀	♂	♀	♂	
Columbia River, 8/22-11/20, 1914	N M SD	52 16.46 1.52	1(?) 18.50	352 30.20 2.87	379 29.54 1.79	3 16.01	.....	35 29.80 2.57	50 29.22 1.87	.....	872
Fraser (1921), Fraser River, 1917	N M SD	.....	.....	43 22.98 2.13	46 23.56 1.29	.....	.....	.....	.....	.....	89
Fraser (1921), Nanaimo, 1917	N M SD	.....	.....	234 22.75 2.00	270 22.37 1.56	.....	.....	.....	.....	.....	504
Fraser (1920), Strait of Georgia, 7/7-10/6, 1916	N M SD	28 13.82 1.54	.....	999 22.11 2.08	973 22.07 1.67	.....	.....	.....	.....	.....	2,000
Fraser (1921), Quathiaski, 1917	N M SD	.....	.....	159 22.03 1.19	248 21.71 1.02	.....	.....	.....	.....	.....	407
Fraser (1921), Lasqueti, 1917	N M SD	.....	.....	199 21.40 1.51	222 21.76 1.12	.....	.....	.....	.....	.....	421
Pritchard (1940), British Columbia, 1925-1930	N M SD	7		6,179		2		54		.....	6,242
Gilbert (1922), Yukon River, 6/15-7/31, 1920	N M SD	.....	.....	6 23.8*	4 24.6*	.....	.....	11 24.5*	6 25.3*	1 23.0*	28

*These figures are Gilbert's; all other means and standard deviations have been calculated for this paper.

imens of 2_1 fish, 11 of 3_1, 4 of 4_1, 46 of 4_2, 2 of "older types" given by Pritchard (1940), and 1 of 5_4 given by Gilbert (1922). In general, there seems to be a tendency for younger fish to be relatively more abundant in the south, and for older fish to be relatively more abundant in the north. However, ages, as determined by Fraser and Pritchard, seem to differ from ages as determined for this paper and as determined by Gilbert, in that Fraser has reported no 4_3 fish, and Pritchard very few of this age class; and, in addition, the latter has recorded fish that had apparently gone to sea as fry. Chamberlain (1907: 44), speaking of silver salmon fry in Alaska, says that "....the greater part seek the sea as soon as they become free-swimming." Gilbert (1913a: 16) states that "....very few individuals of undoubted sea type have been examined," but gives no definite number. Fraser (1917: 42), in reference to scale examinations of nearly 400 individuals from Neah Bay, remarks that "....only three showed indication of going to sea as fry," but later (1920: 196) states that "The three .... reported from Neah Bay were

dog salmon....." Fraser (1921) and Gilbert (1922) report no fry migrants from British Columbia and the Yukon River, respectively. Pritchard (1940) records silvers that had gone to sea as fry, as noted above; however, he also points out that the percentage of this type is very small, and that Chamberlain's record of a high percentage of fry migrants was probably due to the fact that some of the fry do migrate downstream, and then later return upstream, without entering salt water. The latter migration was probably overlooked by Chamberlain. It is also possible that Chamberlain was in error as to the species.

Table 19. Silvers: comparison of the percentage of age classes in samples from different localities

Source	Year	2_2		3_2		3_3		4_3		N
		N	%	N	%	N	%	N	%	
Columbia River	1914	53	6.1	731	83.9	3	0.3	85	9.7	872
Fraser River Fraser (1921)	1917	..	...	89	100.0	..	...	..	....	89
Nanaimo Fraser (1921)	1917	..	...	504	100.0	..	...	..	....	504
Strait of Georgia Fraser (1920)	1916	28	1.4	1,972	98.6	..	...	..	....	2,000
Quathiaski Fraser (1921)	1917	..	...	407	100.0	..	...	..	....	407
Lasqueti Fraser (1921)	1917	..	...	421	100.0	..	...	..	....	421
British Columbia Pritchard (1940)	1925- 1930	7	0.1	6,179	97.9	2	+	54	0.9	6,312
Yukon River Gilbert (1922)	1920	..	...	10	35.7	..	...	17	60.7	28

These disagreements are probably not important in consideration of the commercial catch, since the 3_2 age class is undoubtedly the dominant one in the fishery. However, if ages as reported here and by Gilbert are correct, and if there is a fairly orderly south-to-north change in the percentage of age classes, then it is to be expected that the percentage of 4_3 fish in the silver salmon populations of British Columbia is higher than previous work has shown. If these older fish are more abundant in the early parts of the runs, it may be that these portions of the runs have been undersampled in the British Columbia collections.

Data on growth have been given by Fraser (1921) for 3_2 males and females combined. These are compared with similar data, as determined for Columbia River silvers, in Table 20, with the annual growth increments expressed as percentages of the length at maturity. At first inspection, it would seem that the fish from British Columbia grew more in their first year, less in their second, and more in their third year, than did the fish from the Columbia. However, because of Fraser's method of correcting for initial fish growth before scale formation (see explanation in section on chums), it would be expected that the first year's growth for British Columbia fish, as calculated by him, would be greater than that calculated here for the Columbia River fish. Also, because Fraser's fish were taken in coastal waters, before they entered the spawning streams, it would be expected that the last year's

growth would be less for the British Columbia fish than for the Columbia River fish, which were taken in the river, and thus had had a longer period of growth in the sea. However, if the correction for initial fish growth is removed from the averages as given by Fraser, the resulting calculated lengths agree closely with those for the Columbia River fish. An example of these calculated lengths without correction is given for the Quathiaski fish (see "without correction" in Table 20); and this shows that the relative amount of growth in the fish from the two localities agrees closely for the first year, is somewhat less for the British Columbia fish in the second year, and somewhat more for the British Columbia fish in the last year. This latter difference probably would be increased if the British Columbia fish had been taken from a comparable (later) part of the run.

Table 20. Silvers: comparison of growth, expressed as annual increments in percentage of length at maturity, in samples from different localities

Source	1_1	2_2	3_2
Columbia River	9.3	55.0	35.8
Quathiaski			
Corrected	16.1	48.2	36.2
Without correction	9.3	50.7	38.5
Lasqueti	16.2	48.2	35.7
Fraser River	15.9	46.4	37.8
Nanaimo	16.0	47.6	36.9

The length-weight curve for Columbia River silver salmon, males and females combined, and unweighted average weights at each length for male and female silvers from the Nanaimo cannery, as given by Fraser (1921: 19, 20), are shown in Figure 23. Since Fraser measured length to the base of the caudal fin, and not to

Table 21. Silvers: comparison of sex ratios in samples from different localities

Source	N	2_2	3_3	3_2	4_3	Total
		♂♂/♀♀	♂♂/♀♀	♂♂/♀♀	♂♂/♀♀	♂♂/♀♀
Columbia River........	872	52/1	3/0	0.93	0.70	1.02
Fraser River..........	89	....	...	0.93	....	0.93
Nanaimo...............	504	....	...	0.87	....	0.87
Strait of Georgia.....	2000	28/0	...	1.03	....	1.06
Quathiaski............	407	....	...	0.64	....	0.64
Lasqueti..............	421	....	...	0.90	....	0.90
Yukon River...........	31	....	...	1.50	1.83	1.80

the end of the middle caudal rays, it is to be expected that his fish would appear heavier for a given length than those from the Columbia; but, even if allowance is made for this, the curve for the Nanaimo silvers is steeper than that for the Columbia River fish. Apparently, the length-weight relationships differ, and the British Columbia fish are relatively heavier.

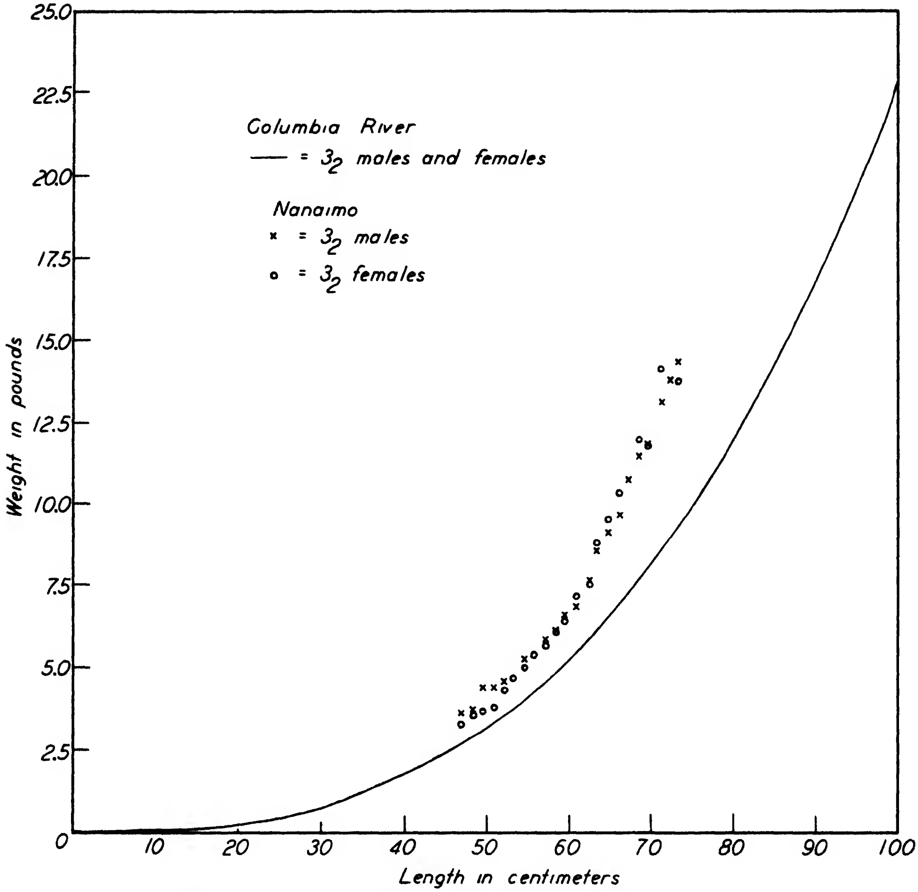

Fig. 23. Silvers: comparison of the length-weight relationship in samples from the Columbia River and Nanaimo.

The sex ratios for the total collections for each locality are shown in Table 21. The two marked deviations from the expected equal representation of males and females occur in the samples from Quathiaski (females in excess), and the Yukon River (males in excess). Possible causes of these deviations have been discussed in the consideration of the chum salmon and will not be repeated here.

As in the chum salmon runs, the silver salmon runs occur earlier in the year with increasing latitude of the stream in which they spawn. In the Klamath and Columbia Rivers the major part of the run is in September, October, and November; in British Columbia waters it is slightly earlier; and in the Yukon River it is in July and August.

It is felt that differences similar to those described above may be demonstrated between the races of silver salmon entering the Columbia River. As with the chums, such knowledge may be of the utmost importance in sampling the commercial

catch, and in regulating the fishing intensity in accordance with the escapement necessary to maintain the particular races passing through the fishery at that time.

SUMMARY

Samples, consisting of scales, length and weight measurements, and sex determinations of chum, pink, and silver salmons, were taken from the commercial catch in the Columbia River in 1914.

Five hundred eighteen chum scales were examined. All fish had gone to sea early in their first year; and 70.5 per cent had returned in their third year, 28.7 per cent in their fourth, and 0.8 per cent in their fifth. Growth curves, based on scale and fish measurements, are given for all sex-age groups. The length-weight relationship may be expressed by the equation $\text{Weight}=0.0001378\times\text{Length}^{2.6004}$. Tendencies were noted, during the course of the run, for older fish and for males to be relatively more abundant in the earlier portions of the run. In comparisons with data from other localities, it was demonstrated that, from south to north: (1) there is a decrease in mean length at the same age; (2) older fish are progressively more abundant; and (3) the runs are progressively earlier.

Pink salmon are uncommon in the Columbia River, and only six were examined. All had gone to sea early in their first year, and all had returned in their second year.

Eight hundred eighty-five silver salmon scales were examined. Of the total, 6.1 per cent had gone to sea early in their second year, and returned late in their second year (2_2); 0.3 per cent had gone to sea early in their third, and returned late in their third (3_3); 83.9 per cent had gone to sea in their second, and returned in their third (3_2); and 9.7 per cent had gone to sea in their third year, and returned during their fourth year (4_3). Growth curves are given for all age groups. The length-weight relationship may be expressed by the equation $\text{Weight}=0.0000373\times\text{Length}^{2.8945}$. As in the case of the chums, changes were noted during the run in the sex ratio and the percentage of age classes. Comparison with data from other localities revealed south-to-north changes in size and in abundance of different age groups, similar to those demonstrated for the chums.

It is felt that the differences between races of a single river system will prove to be of the same nature as those here demonstrated between populations of different river systems. Knowledge of the differences between the races of salmons entering the Columbia River may be of extreme importance in the management of the fisheries.

LITERATURE CITED

CHAMBERLAIN, F. M.
1907 Some observations on salmon and trout in Alaska. U.S. Bureau Fisheries Doc. no. 627, 112 pp., 5 pls.

CLARK, Frances N.
1925 The life history of *Leuresthes tenuis*, an atherine fish with tide controlled spawning habits. Calif. Fish & Game Comm., Sacramento, Fish. Bull. no. 10, 51 pp., 17 figs.

CRAIG, Joseph A., and Robert L. HACKER
1940 The history and development of the fisheries of the Columbia River. Bull. U.S. Bureau Fisheries, vol. 49, no. 32, pp. 133-216, 16 figs.

CREASER, Charles W.
1926 The structure and growth of the scales of fishes in relation to the interpretation of

their life history with special reference to the sunfish, *Eupomotis gibbosus*. Univ. Michigan Mus. Zool , Ann Arbor, Misc. Publ. no. 17, 82 pp., 12 figs., 1 pl.

DAHL, Knut

1911 The age and growth of salmon and trout in Norway as shown by their scales. (Translated from the Norwegian by Ian Baillee.) The Salmon and Trout Assoc., 141 pp., 32 figs., 10 pls. London.

DAVIDSON, F. A.

1940 Age, growth, and seasonal time of migration of the Pacific salmon as an indication of environmental conditions in the sea. Proc. Sixth Pacific Sci. Congress, vol. 3, p. 533. Berkeley.

DUNLOP, H. A.

1924 The growth-rate of the scales in the sockeye salmon, *Oncorhynchus nerka*. Contribs. Canadian Biol., Toronto, N.S., vol. 2, no. 10, pp. 153-159, 2 figs.

EVERMANN, Barton Warren, and Edmund Lee GOLDSBOROUGH

1907 The fishes of Alaska. Bull. U.S. Bureau Fisheries, vol. 26, for 1906, pp. 219-360, 144 figs., pls. 14-42.

FISHER, R. A.

1925 Statistical methods for research workers. Pp. ix + 239, 10 text-figs. Edinburgh.

FRASER, C. McLean

1916a Growth of the spring salmon. Trans. Pacific Fisheries Soc., Seattle, for 1915, pp. 29-35.

1916b Ichthyological notes on: II. *Oncorhynchus keta* Walbaum. Trans. Roy. Canadian Instit., Toronto, pp. 109-118, figs. 26-29, pl. 10.

1917 On the life-history of the coho. Contribs. Canadian Biol., Ottawa, for 1915-1916, pp. 39-52, 13 figs.

1920 Growth rate in the Pacific salmon. Trans. Roy. Soc. Canada, Ottawa, ser. 3, vol. 13, for 1919, sect. 5, pp. 163-226, 22 figs.

1921 Further studies on the growth rate in Pacific salmon. Contribs. Canadian Biol., Ottawa, for 1918-1920, pp. 7-27.

GILBERT, Charles H.

1913a Age at maturity of the Pacific Coast salmon of the genus *Oncorhynchus*. Bull. U.S. Bureau Fisheries, vol. 32, for 1912, 22 pp., 17 pls.

1913b The salmon of Swiftsure Bank. Rept. Comm. Fisheries (British Columbia) for 1912, Victoria, Appendix, pp. I 14-I 18.

1922 The salmon of the Yukon River. Bull. U.S. Bureau Fisheries, vol. 38, for 1921-1922, pp. 317-332, figs. 276-302.

GILBERT, Charles H., and Willis H. RICH

1927 Investigations concerning the red-salmon runs to the Karluk River, Alaska. Bull. U.S. Bureau Fisheries, vol. 43, part II, pp. 1-69, 34 figs.

HILE, Ralph, and Frank W. JOBES

1941 Age, growth, and production of the yellow perch, *Perca flavescens* (Mitchill), of Saginaw Bay. Trans. American Fisheries Soc., Washington, vol. 70, pp. 102-122, 5 figs.

JOHNSTON, H. W.

1905 The scales of the Tay salmon as indicative of age, growth, and spawning habit. Twenty-third Ann. Rept. Fisheries Board Scotland, Glasgow, for 1904, part II, pp. 63-79, 6 pls.

KATAYAMA, Masao

1935 Biometric study of dog salmon, *Oncorhynchus keta* (Walbaum). Bull. Jap. Soc. Sci. Fish., Tokyo, vol. 4, no. 3, pp. 171-173.

KUBO, Ituo

1938 Preliminary notes on the stock of anadromous dog salmon *Oncorhynchus keta* (Walbaum). I. On the catch from the Mimoto River. Bull. Jap. Soc. Sci. Fish., Tokyo, vol. 6, no. 5, pp. 262-265.

McMURRICH, J. Playfair

1909 The life history of the Pacific salmon. Trans. Canadian Instit., Toronto, vol. 9, pp. 23-44, 3 figs.

1912 The life cycles of the Pacific Coast salmon belonging to the genus *Oncorhynchus*, as revealed by their scale and otolith markings. Proc. & Trans. Roy. Soc. Canada, Ottawa, ser. 3, vol. 6, sect. IV, pp. 9-28, 10 pls.

1913a Some further observations on the life histories of the Pacific Coast salmon as revealed by their scale markings. Trans. Roy. Soc. Canada, Ottawa, ser. 3, vol. 7, sect. IV, 10 pp., 5 figs.

1913b Salmon fisheries of British Columbia. Fourth Ann. Rept. Comm. Conservation, Ottawa, 13 pp., 6 figs.

MOTTLEY, C. McC.

1942 The use of the scales of the rainbow trout (*Salmo gairdnerii*) to make direct comparisons of growth. Trans. American Fisheries Soc., Washington, vol. 71, for 1941, pp. 74-79.

PRITCHARD, Andrew L.

1932 Pacific salmon migration: The tagging of the pink and chum salmon in British Columbia in 1929 and 1930. Biol. Board Canada, Ottawa, Bull. 31, 16 pp., 5 figs.

1936 Facts concerning the coho salmon (*Oncorhynchus kisutch*) in the commercial catches of British Columbia as determined from their scales. Progress Rept. Pacific Biol. Sta., Nanaimo, B.C., and Pacific Fisheries Exp. Sta., Prince Rupert, B.C., Prince Rupert, no. 29, pp. 16-20, 5 figs.

1940 Studies on the age of the coho salmon (*Oncorhynchus kisutch*) and the spring salmon (*O. tschawytscha*) in British Columbia. Trans. Roy. Soc. Canada, Ottawa, ser. 3, vol. 34, sect. V, pp. 99-120, 2 pls.

1943 The age of chum salmon taken in the commercial catches in British Columbia. Progress Rept. Pacific Biol. Sta., Nanaimo, B.C., and Pacific Fisheries Exp. Sta., Vancouver, B.C., Vancouver, no. 54, pp. 9-11.

RICH, Willis H.

1920 Early history and seaward migration of chinook salmon in the Columbia and Sacramento Rivers. Bull. U.S. Bureau Fisheries, vol. 37, for 1919-1920, 73 pp., 4 pls.

1942 The salmon runs of the Columbia River in 1938. U.S. Fish & Wildlife Service, Fish. Bull., vol. 50, pp. 103-147, 8 figs.

1943 An application of the control chart method to the analysis of fisheries data. Science, Lancaster, Penna., N.S., vol. 97, no. 2516, pp. 269-270, 1 fig.

ROUNSEFELL, George A., and George B. KELEZ

1938 The salmon and salmon fisheries of Swiftsure Bank, Puget Sound and the Fraser River, Bull. U.S. Bureau Fisheries, vol. 49, no. 27, pp. 693-823, 29 figs.

SIMPSON, George Gaylord, and Anne ROE

1939 Quantitative zoology. Pp. xvii + 414, 52 text-figs. New York.

SNEDECOR, George W.

1934 Calculation and interpretation of analysis of variance and covariance. 96 pp. Ames, Iowa.

1937 Statistical methods. Pp. xiii + 341, 21 text-figs. Ames, Iowa.

SNYDER, John O.

1931 Salmon of the Klamath River, California. Calif. Fish & Game Comm., Sacramento, Fish. Bull. no. 34, 130 pp., 44 figs.

VAN OOSTEN, John

1929 Life history of the lake herring (*Leucichthys artedi* Le Sueur) of Lake Huron as revealed by its scales, with a critique of the scale method. Bull. U.S. Bureau Fisheries, vol. 44, for 1928, pp. 265-428, 43 figs.

WEYMOUTH, F. W., H. C. MCMILLIN, and W. H. RICH

1925 The regression of age with size, a neglected aspect of growth. Proc. Soc. Experi. Biol. Medicine, Utica, N.Y., vol. 22, pp. 339-342.

CONTRIBUTION TO THE BIOLOGY OF THE ALBACORE (*GERMO ALALUNGA*) OF THE OREGON COAST AND OTHER PARTS OF THE NORTH PACIFIC[1]

By Vernon E. Brock

INTRODUCTION

In 1937 the albacore, *Germo alalunga* (Gmelin), perhaps the most valuable of all the tunas, was found in large numbers off the Oregon coast and since then has been the object of an intensive fishery. Canneries have been established, boats have been built, various other provisions have been made for the exploitation of these fish and the market has come to depend upon this fishery as an important source of supply. The new industry is of very considerable economic importance to the state but the soundness of the development must, obviously, depend on the stability of the supply of fish that provides the raw material. If the resource is such that it may reasonably be expected to yield a constant supply the development is sound. If, on the other hand, the supply is likely to fail through over-fishing, or the fish to be irregular in their appearance on the fishing grounds for some unknown causes, the industry may suddenly fail and serious economic disturbance result. Some 25 or 30 years ago albacore were abundant off the coast of California and formed the basis of a productive fishery. Suddenly, however, the abundance was greatly reduced and the fish have not again appeared in anything like their former numbers. This has given rise to the opinion, perhaps justified, that the albacore fishery of the eastern Pacific is likely to prove an unstable one.

The cause, or causes, of the sudden reduction in the abundance of the albacore off the coast of California has never been determined. It has been variously explained as the consequence of over-exploitation, of the incidence of a series of years in which, for one reason or another, reproduction or survival of the young was poor, or as a result of a shift in the geographic distribution of the species. Whether the albacore appeared in abundance suddenly off the Oregon coast or whether the species had been there in years prior to 1937 is not known. If it did appear suddenly the cause of this is not known. Because the species is wide in its distribution over the north Pacific it has been impossible to satisfactorily answer these questions with the available data which are, for the most part, local in nature. Yet, obviously, these questions must be answered if the industry is to plan its future investments prudently and if conservation agencies, such as the Oregon Fish Commission, are to determine their policies on a rational basis.

Shortly after the albacore fishery was started in Oregon, the Department of Research of the Fish Commission of Oregon initiated a program of research into the biology of the albacore and the albacore fishery. This paper presents the results of the first four years of this study. It describes certain biological features of the albacore populations of the Pacific Coast with emphasis on those of Oregon and presents a review of all available material on the species from other parts of the north Pacific insofar as this material bears on the fishery problems.

The development of the albacore fisheries of our Pacific Coast began about 1910 but no accurate data as to the catch are available for the years prior to 1916. Up to 1936 the fishery was confined strictly to California waters and the record of the catch during the period from 1916 to 1935 is given graphically in Figure 20 of Fish Bulletin 49 of the California Division of Fish and Game (1937). The Oregon fishery began when, on August 11, 1936, the pilchard boat "Robin" took about one ton of albacore on regular tuna gear off Coos Bay. This was shipped to California together with approximately five additional tons taken shortly after by

[1]Contribution No. 10 from the Department of Research, Fish Commission of Oregon.

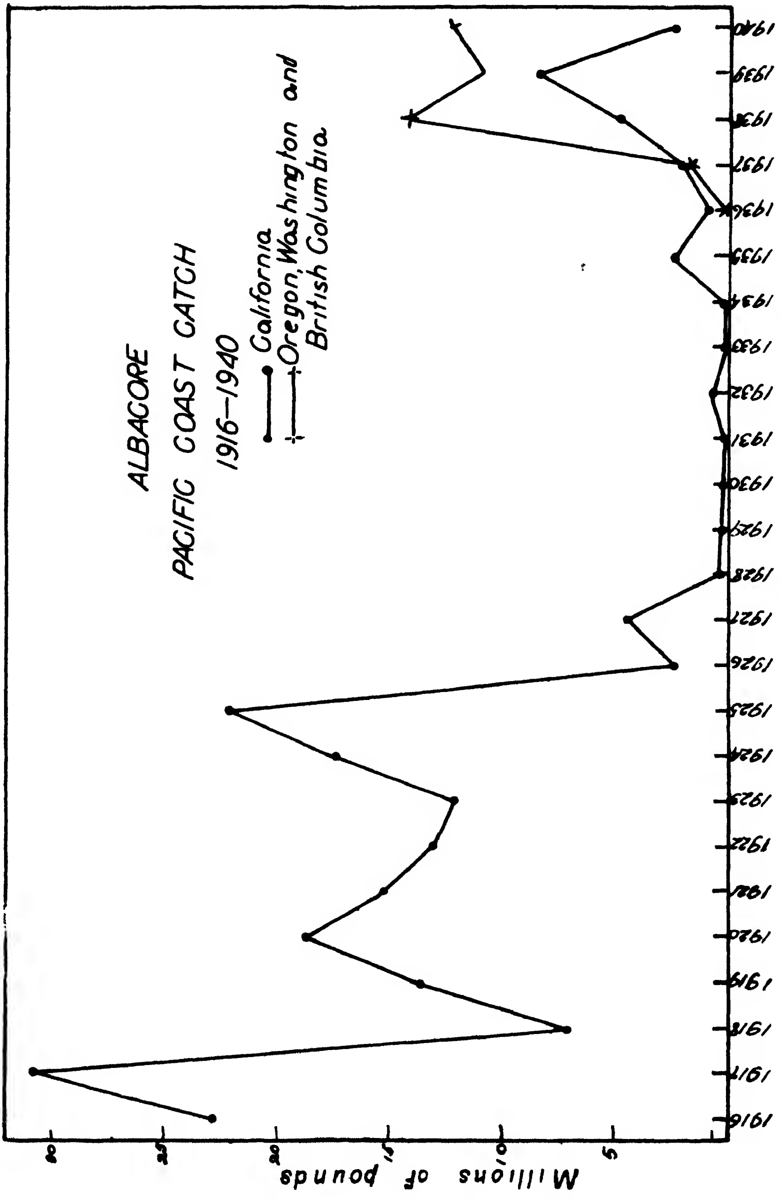

Fig. 1. Pacific Coast catch of albacore, 1916-1940. The data were taken, in part, from Figure 20 of Fish Bulletin 49, California Division of Fish and Game, which shows the California landings from 1916 to 1935 inclusive.

pilchard boats. This is believed to be the first commercial catch of albacore in the northwest. The statistics of our Pacific albacore fishery from 1936 to 1940 are given in Table 1 and have been compiled from figures given in Fish Bulletins 57 (1940) and 58 (1942) of the California Division of Fish and Game, and from records in the office of the Master Fish Warden of the Oregon Fish Commission. Figure 1 shows graphically the entire record since 1916.

Table 1. Catch of Pacific Coast albacore, 1936-1940, in pounds

	1936	1937	1938	1939	1940
Grand total..........	956,771	3,706,090	18,917,309	19,206,645	14,505,463
Caught and delivered in California......	945,595	2,020,016	4,789,880	8,264,109	2,331,932
Caught off northwest coast:					
Total..............	11,176	1,686,074	14,127,429	10,942,536	12,173,531
Delivered in Calif.			1,995,101	1,732,066	1,552,504
Delivered in Ore...	11,176	1,353,522	8,000,000	6,484,795	9,286,261
Delivered in Wash..		332,552	4,132,328	2,441,875	1,330,266
Delivered in B.C...				283,800	4,500
Caught and delivered off nortnwest coast transhipped to Calif.	11,176	1,176,754	5,707,694	2,346,496	1,703,354
Total delivered and shipped to Calif. from northwest coast..............	11,176	1,176,754	7,702,795	4,078,562	3,255,858

The albacore is a pelagic fish and apparently roams over vast distances, perhaps occurring in different places at particular phases in its life history. It seems probable that a clear-cut picture of the life history, migrations, and population biology of the species will be obtained only through a broad study covering the entire geographical range of the species. At present only scattered series of data and some isolated observations are at hand for study. These include a series of length measurements made from 1924 to 1928 by the California State Fisheries Laboratory at San Pedro, a similar series made from 1938 to 1941 by the Oregon Fish Commission, data taken from Japanese fishery bulletins, some chance observations of albacore taken in mid-Pacific and, finally, some miscellaneous data on Hawaiian albacore. (Other data, not available for this study, were collected by Dr. W. F. Thompson of the International Pacific Salmon Commission about 20 years ago while he was director of the California State Fisheries Laboratory. It is hoped that publication will eventually make these data available to other workers.)

Although limited, the data presented in this report provide the most complete information on the albacore of the north Pacific now available. There are large gaps remaining to be filled, yet a certain pattern of life history is evident and some working hypotheses can be set up that will be useful in directing the future development of the industry and measures for the conservation of the resource.

The important section on the California albacore could not have been written except for the generous manner in which the California Division of Fish and Game made available its seasonal summaries of the length frequencies of albacore landed

at San Pedro during the years 1924 to 1928 inclusive. Thanks for this are due especially to Mr. W. L. Scofield and Dr. Frances N. Clark of the California State Fisheries Laboratory. Dr. Clark also gave freely of her time and advice in the study of the data. The librarian at the laboratory, Miss Katherine Karmelich, was of great help in locating some of the pertinent literature.

Dr. Seiji Konda, of the Higher School of Fisheries, Hakodate, Japan, sent a number of issues of the Bulletin of the Japanese Society of Scientific Fisheries containing articles on albacore and the albacore fishery of Japan. He also sent a series of scales from Japanese albacore that proved to be most interesting.

During a portion of this study, working space, calculating machines and other equipment were provided in the laboratory of the U. S. Fish and Wildlife Service, South Pacific Investigations, at Stanford University. Acknowledgement is made of the friendly advice and assistance given by Mr. O. E. Sette and Dr. L. A. Walford of that laboratory. The ingenious scheme of curve fitting used here in identifying modal groups in the Oregon length frequencies is a simplification of a more critical, and as yet unpublished, method devised by Mr. Sette.

Through the kindness of Dr. George S. Myers, laboratory quarters and various facilities were supplied the author in the Natural History Museum of Stanford University. For these favors and many others the author expresses sincere thanks.

The cooperation of many persons engaged in the Oregon albacore industry—fishermen, cannery workers, and cannery officials—have made the collection of data much easier and more complete than it might have been otherwise. Although it is impossible here to extend individual thanks to all those concerned, the author wishes to express his gratitude for such aid, as best he may, collectively.

Lastly, thanks are due to Dr. Willis H. Rich, under whose directorship this work was done, and to Mr. M. T. Hoy, Master Fish Warden of the Oregon Fish Commission, whose administrative assistance has frequently smoothed the way.

CALIFORNIA ALBACORE

For various cogent reasons it seems desirable to begin this study with an analysis of the data on the California albacore fishery. This was the first major albacore fishery on the Pacific Coast of North America and, therefore, has had the most extended history. That history includes an initial period of growth and profitable operation followed abruptly by a long period of poor catches and of economic loss to those dependent upon this fishery (Fig. 1). Only in recent years has the fishery shown evidence of recovery. The pattern of this failure has been described here as completely as possible from the few data available, with the thought that this will aid in the early recognition of similar failures in other albacore fisheries, if such should occur. Furthermore, this longer history of the California fishery shows clearly certain persistent characteristics of the exploited population and gives a background for the study of the more recent albacore fishery of Oregon.

THE LENGTH-FREQUENCY DISTRIBUTIONS.—The California measurements were made by means of a steel tape stretched from the end of the snout over the side of the body to the tip of the mid-caudal ray. The data were received by the author in the form of length-frequency tabulations for each season and without indication of the number or distribution of the individual samples within the seasons. The measurements had been recorded to the nearest millimeter and later combined into centimeter classes. The grouping into these centimeter classes was not uniform; one combination was used for the data of 1924 and another for the later years. This accounts for the different values of the class centers as given in Table A of the

Appendix. This minor defect in the data might have been remedied by retabulating the original measurements but is so slight as to be of no practical importance. The data are given in full in Table A of the Appendix and are plotted in Figure 2. Each

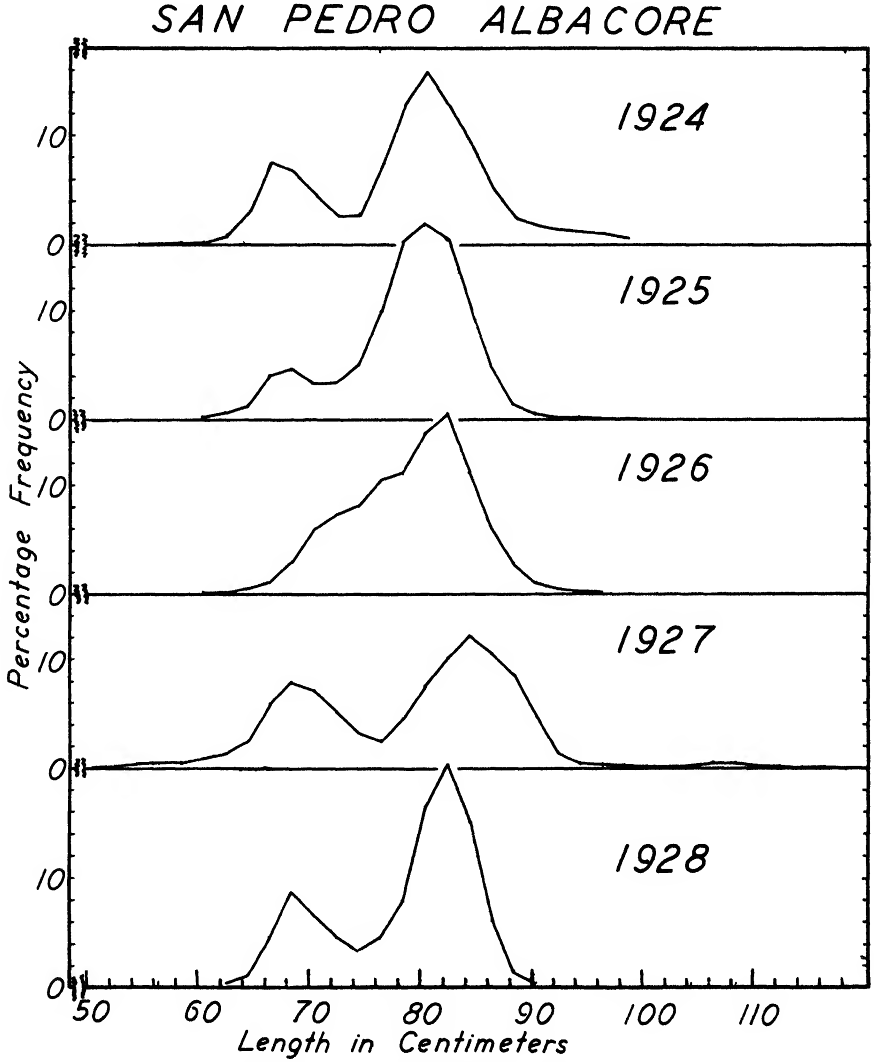

Fig. 2. Length-frequency curves, San Pedro albacore, 1924-1928. The measurements for 1924 and 1927 extend beyond the limits of the figure. See Table A, Appendix, for details. For the purposes of graphing, the classes of Table A were combined in groups of two by adding each even-numbered class and the next higher odd-numbered class.

of the five length-frequency distributions is distinctly bimodal and the two modes occur at about the same lengths in each of them. This consistency and the simplicity of the curves shown in Figure 2 strongly suggest that the fish belong to a common stock and that two age groups, one a year older than the other, normally dominate the catch. If this be true, then the smaller group in one year and the larger in the next represent fish of the same brood year.

To simplify the discussions of these modal groups, the group of smaller fish with modal lengths from 68.1 to 72.2 centimeters (Table 2) will be referred to as "group A" and the group of larger fish, modal lengths from 80.3 to 85.0 centimeters, as "group B."

The methods used to ascertain the modal lengths were as follows: for each modal group the mean of the five adjacent classes that contained the greatest number of individuals was taken as the mode. This method proved satisfactory for all the length-frequency distributions except that of 1926. In 1926 the A and B groups overlapped to such an extent that the modal position of A was obscured (Fig. 2). This mode was estimated graphically by drawing a straight line from the peak of the curve (i.e., from the center of the largest class) over the position of group A to the origin of the curve near the X-axis. The five adjacent classes that approached nearest to the line were averaged and this value taken as the mode.

Table 2. Modal lengths of San Pedro albacore, 1924-1928 (in centimeters)

Year	Mode A	Mode B	Direct Difference (1)	Lagged Difference (2)
1924	68.085	80.302	12.217	12.901
1925	68.070	80.986	12.916	13.941
1926	72.230	82.011	9.781	12.802
1927	69.047	85.032	15.985	13.081
1928	69.018	82.128	13.110	

In Table 2 are given the modal lengths of each group for each year, and (1) the difference between groups A and B in the same year (the "direct difference"), and (2) the difference between group A in one year and group B in the next (the "lagged difference"). The standard deviations of the two distributions of differences have been calculated and found to be 2.22 for the difference between group A and B for the same year, but only 0.52 for the difference between group A in one year and group B the following year. It may be seen that the direct differences are much less uniform than the lagged differences. The greater uniformity of the latter suggests that variations in the modal positions of group A for a given season are associated with those of group B for the following season and not with those of group B for the same season. Statistical evidence favoring this hypothesis is given by the existence of a significant correlation between the modal position of group A for one year and that of group B for the next ($r = +.97$ and $P < .05$). The coefficient of correlation between the modal positions of groups A and B for the same season is not significant ($r = +.19$ and $P > .7$).

These results are consistent with the following conclusions: the albacore catch landed at San Pedro, California, from 1924 to 1928 was dominated by two adjacent year classes here designated A and B. Judging from the form of the length-frequency curves, other ages, if present, were unimportant. A given year class appeared in substantial amounts in the catch for only two successive seasons.

Evidently the California fishery was landing a selected portion of the alba-

core population. While the causes of such a selection are not known and may have been due to the fishing methods and equipment, it seems probable that the albacore population in California waters was fairly represented by the samples and was composed largely of two year classes.

RELATIVE ABUNDANCE OF MODAL GROUPS A AND B.—It would appear from Figure 2 that the number of fish in group A was consistently lower than that in group B. If the assumption be made that only groups A and B were present, their relative proportions could be estimated by the following methods. (1) The frequency distributions for each season were divided into two parts at the upper boundary of the class between the modes of groups A and B that had the fewest individuals. This class and all fish shorter were ascribed to group A and the remainder of the length-frequency distribution to B. (2) Because of the overlapping between groups A and B in the length-frequency distribution for 1926 another method was used. For that year the point of division was selected by eye, employing as a guide two normal frequency distributions the modes of which coincided with the modes of groups A and B. The results are presented in Table 3. Group A constitutes between 14 and 36.4 per cent of the fish sampled and probably a closely similar percentage of the fish landed. The proportion of group A to B seems to be fairly consistent and to be maintained in spite of wide fluctuations in the catch (see Fig. 1).

Table 3. Percentage of A and B groups in San Pedro albacore, 1924-1928

Year	Percentage of Group A	Percentage of Group B
1924	24.3	75.7
1925	14.0	86.0
1926	30.5	69.5
1927	36.4	63.6
1928	26.3	73.7

The numbers of fish landed belonging to each group were calculated by a method to be described later (see p. 208) and these numbers are plotted in Figure 3. This figure graphically illustrates the consistently smaller numbers of fish of the A group as compared to those of the B group, notwithstanding wide fluctuations in the volume of landings. The coefficient of correlation between the numbers of A and B fish in the same year has been calculated and is of borderline significance ($r=.86$ and $P=.07$). By contrast the coefficient of correlation between the number of fish in group A in one year with that of group B in the year following is clearly not significant ($r-.76$ and $P-.33$).

It would not be unreasonable to expect that fluctuations in abundance of groups A and B in the sea would be, within limits, independent. Likewise the fluctuations in the number of fish landed from each of these two groups would be expected to be independent of each other and dependent upon the fluctuations in abundance of each in the sea. However, the first coefficient of correlation ($r-.86$) would seem to indicate, if it be truly significant, that fluctuations in numbers of group A fish are not independent of the fluctuations of group B fish in the landings. If the landings of group A fish are coupled by some unknown mechanism with those of group B, that same mechanism may also be responsible for the lesser absolute numbers of A fish in the catch as compared to B fish within any given season (see Fig. 3). It would seem probable that group A would be, in general, the more abundant since it is the younger. Its lesser abundance in the landings may be

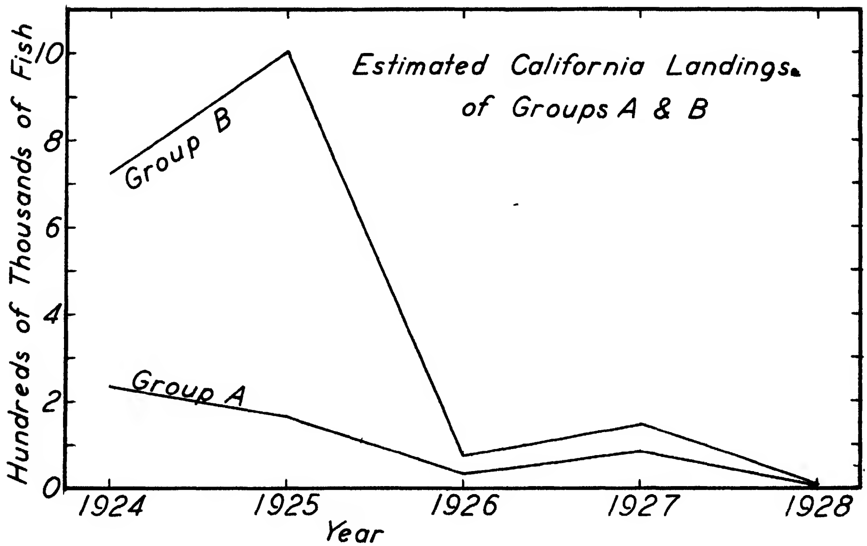

Fig. 3. Estimated California landings of groups A and B, 1924-1928.

from the effects of gear selection although it seems doubtful that gear selection alone could give rise to a correlation between the landings of the two groups. It is not intended to imply, of course, that gear selection may play no part in the lesser number of group A fish landed. It is only suggested here that whatever mechanism relates the numbers of A and B fish in the landings may also be responsible for the lesser number of A fish, and further, that that mechanism is probably not gear selection. No satisfactory explanation can be offered with the data available but it is possible that the two groups remain on the fishing ground for different periods, the larger fish remaining longer and allowing a greater catch which is, nevertheless, proportional to the catch of the smaller fish. This will be considered more fully in the discussion of the Oregon fishery.

The existence of only two size groups (or age groups) has been assumed in these discussions. However, it is almost certain that others were present at least in small numbers. The skewness of the right side of the length-frequency curves in Figure 2 probably results from the presence of such a group or groups. If the group B length-frequency distribution is assumed to be normal in form, few if any fish belonging to this group would be found longer than 95 or 100 centimeters; yet fish as long as 125 centimeters are represented in the samples. However, the proportion of fish above 100 centimeters is relatively small, from .024 to 2.63 per cent (see Table 4), and consequently any errors introduced by considering these fish part of group B should likewise be small.

FLUCTUATIONS IN ABUNDANCE.—The length-frequency data from San Pedro cover a most interesting period. During this period occurred the spectacular failure of the fishery which began with the season of 1926 (see Fig. 1). This failure was sudden and nearly complete. From 1916 to 1925 the average annual catch was over seventeen million pounds, fluctuating between seven and thirty-one million. From 1926 to 1935

Table 4. Percentage of fish occurring in length-frequency measurements greater than 99 centimeters in length for each season: San Pedro albacore, 1924-1928

Year	Percentage
1924	.314
1925	.024
1926	.039
1927	2.630
1928	.071

the average annual catch was less than one million pounds with a maximum of about four and a half million. Since 1935 the California albacore fishery has made some recovery but the annual catch is still far below the pre-1926 level and Monterey rather than San Pedro now appears to be the chief port of landing. The rapidity of the failure of the fishery coupled with its long continuance has given a general impression that our albacore fisheries are likely to be unreliable and transient.

The available data are, unfortunately, insufficient to establish the cause of the failure. The most probable causes appear to be these: (1) failure of the fish to occur over their usual range, of which the fishing grounds are a part; (2) depletion through over-fishing; or (3) an increased mortality from other causes that resulted in a series of year classes marked by reduced abundance. Of these three suggestions, the last two imply an actual reduction in the size of the albacore population while the first does not. It is proposed to examine the available data in the light of the three suggestions made here to see if any of the phenomena of the failure fit into the kind of pattern that would be produced if any one of the hypothetical causes were operating.

As stated above, it is probable that the albacore migrate widely and it may reasonably be assumed that fairly definite routes are followed during these migrations. If, for some reason, the fish fail to migrate as far in a given direction as usual they might well fail entirely to reach areas in which commercial fisheries are conducted. Or, if the migration route was not shifted so far as to cause complete failure of the fishery, a partial failure might result from the fact that only those fish that were near the limit of the reduced range were exposed to the fishery. The fishery would be conducted, in a sense, on the margin of the population, and any effect on the length-frequency distributions would depend on whether or not the fish were differentially distributed by size over the range. If not so distributed, no change would necessarily occur in the sizes of fish landed in spite of possibly great changes in the amounts. Therefore, it is possible that any shifts in the range of the fish would not be detected by an examination of the length-frequency distributions.

Under the second hypothesis any great increase in the mortality rate due to fishing such as would cause serious depletion should evidence itself first through a decrease in the proportion of large fish in the catch (a common response made by populations suffering depletion under intensive exploitation). This effect should appear in the length-frequency distributions plotted in Figure 2, or in Table 4; but, for the period covered by the series, 1924 to 1928, no such effect is indicated. In fact, the proportion of large fish over 100 centimeters in length in the samples was greatest of all in 1927 (Table 4), after the failure occurred, and least in 1925, the best season of the series.

It is possible that a greater proportion of large fish would result from the occurrence of a series of reduced annual broods, as suggested under hypothesis 3 above. In fact, should any great reductions in the recruitment occur from this cause, certain definite changes could be anticipated in the size composition of the catch, and changes in the size composition of the catch would be evidenced in the length-frequency distributions of Figure 2. The exact changes occurring would depend, of course, on the degree of reduction suffered by the individual broods or year classes and whether or not such reduction lasted for only a season or for several successive seasons. For example, the first year that an unusually small year class entered the fishery, group A should form a smaller proportion of the catch than normally. If subsequent year classes were likewise abnormally small, the ratio of the two groups, A and B, would be restored to their former proportions, and as long as the incoming year classes remained of about the same magnitude, no further changes in size composition would occur. However, if in the season following the entrance of a small year class into the fishery, a large, "successful" year class should appear, group A should be more abundant than normally in the landings and, conversely, group B less abundant. In any case, changes in size composition of the catch from this cause would only be expected during the period of transition from one level of abundance to another and once the level of abundance became stable the size composition of the catch would likewise remain stable—neglecting other possible factors.

As shown in Table 3, group A fish constituted from 14.0 to 36.4 per cent of the catch during the series of years for which data are available. This is remarkably uniform considering the great fluctuations in the catch itself. As previously discussed, the number of group A fish in the catch appears to be related to the number of group B fish in the catch rather than to the number of group A fish in the sea. For this reason it is possible that the relative numbers of A and B fish in the catch would give little if any indication of changes in the size composition of the population in the sea.[2] However, it is interesting to note that the smallest proportion of group A fish in the catch occurred in 1925, the season preceding the failure of the fishery. This would be perfectly consistent with the entrance of a series of small year classes into the fishery beginning with 1925, and it is possible that this is what actually happened.

The preceding discussion of the failure of the California fishery has been based only upon the data for the total annual landings. It has been pointed out above, however, that these landings are composed largely of two dominating age groups which are present in more or less constant proportions and it has seemed possible that a more significant picture of the failure of the fishery might be provided by considering the contribution to the catch made by each year class for the two-year period during which it forms an important element in the landings.

The contribution of each year class that entered the fishery during the period covered by the available data may be computed in terms of numbers of fish landed by making the following assumptions: (1) fish older than group B are considered part of that group; (2) the length-frequency distributions are assumed to be representative of the commercial catch; (3) the modal length of each group (A or B) is considered identical with the mean length of the respective group; and (4) the estimated mean weight at the modal size is taken as the mean weight for the size group. For this computation the following data were used: percentage of groups A and B in the length-frequency distributions (Table 3); annual landings (Fig. 1);

[2]By this, the entire albacore population is meant, not merely that part exposed to the California fishery which may have had a size composition similar to that of the commercial landings.

modal lengths of each group (Table 2); and a length-weight equation which has been found satisfactorily to relate weight and length of albacore taken in the Oregon fishery—$W=.000723\times L^3$, where W is the weight of the fish in pounds and L the length of the fish in inches as measured on a measuring board. The length of a fish measured by a tape stretched over the body may be converted to the equivalent of measuring board length by multiplying by .953 (page 224).

The weight of group A fish taken in a given season was estimated by applying the equation

$$\left(\frac{P_A \times MW_A}{P_A \times MW_A + P_B \times MW_B}\right) \times S = W$$

In this, P_A is the percentage of group A fish in the length-frequency distribution for the season in question, MW_A is the mean weight of group A fish, P_B the percentage of group B fish, MW_B the mean weight of group B fish, S the seasonal catch, and W the weight of the group A fish. The weight of the group A fish divided by the mean weight gives the number of group A fish. The weight of group A fish minus the seasonal landings gives the weight of group B fish, which was likewise divided by the mean weight of group B fish to obtain the number of fish landed in that group. All weights are given in pounds. (See Fig. 3.)

By adding the estimated number of group A fish in the landings in one year to the estimated number of group B fish in the next, the total number of fish of a given year class contributing to the catch may be estimated. The results of these computations are plotted in Figure 4. As shown there, while the greatest absolute decline occurred with the year class that first entered the fishery in 1925, every succeeding year class was smaller than the one preceding it. This is in contrast to the weight of the annual catch during the same period which, while declining, did fluctuate. For example, the catch of 1925 was better than that for 1924 and the catch for 1927 was better than that for 1926. The fact that the number of fish of successive year classes consistently declined while the weight of the annual catch fluctuated may give some support to the hypothesis that the failure was the result of a continuing reduction in the size of the incoming year classes and was not due to depletion, or simply to a failure of the fish to appear on the fishing grounds.

It is interesting to note that the rate of decline of the year classes was approximately logarithmic, as shown by Figure 5. During this short period of rapid decline in abundance the landings from each year class, as measured by a line fitted to the logarithms by the method of least squares, averaged only 45 per cent of the landings provided by the preceding year class.

It is possible that, after the initial failure, the catch during subsequent poor years was lowered by the progressive abandonment of the fishery by fishermen. This factor would operate in addition to the reduced availability and would result in an exaggerated rate of decline. It is likely that once the returns to the fishermen fell below a certain level, they would tend to abandon the fishery rapidly as a source of livelihood so that the annual catch might fall rapidly without any further change in the actual abundance for the fish. Any rise in the prices paid the fishermen would, within limits, tend to compensate for this effect. However, the abandonment of the fishery would undoubtedly be one of the first major results of reduced availability and it is altogether likely, if the California albacore fishery had been capable of supporting an increased yield with a fishing effort justified by the economics of the fishery, that an increase would have been forthcoming.

The analysis of the California data presented here would tend to favor the hypothesis that a reduction in the abundance (or availability) of the incoming year classes occurred during the period 1924-1928. However, the analysis has been based necessarily on only a crude measure of the availability of the fish—that pro-

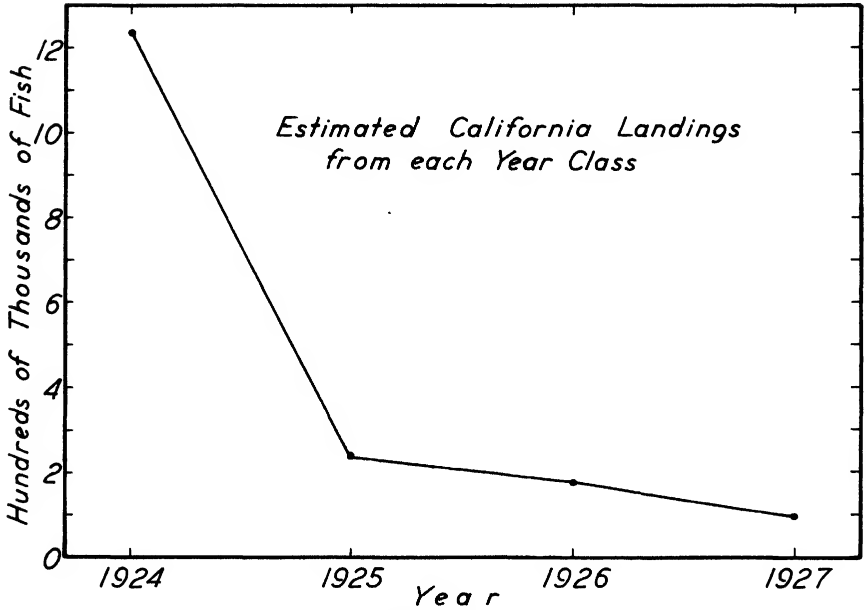

Fig. 4. Estimated California landings from each year class, 1924-1928. The year given is the year in which the year class first entered the commercial fishery as group A fish.

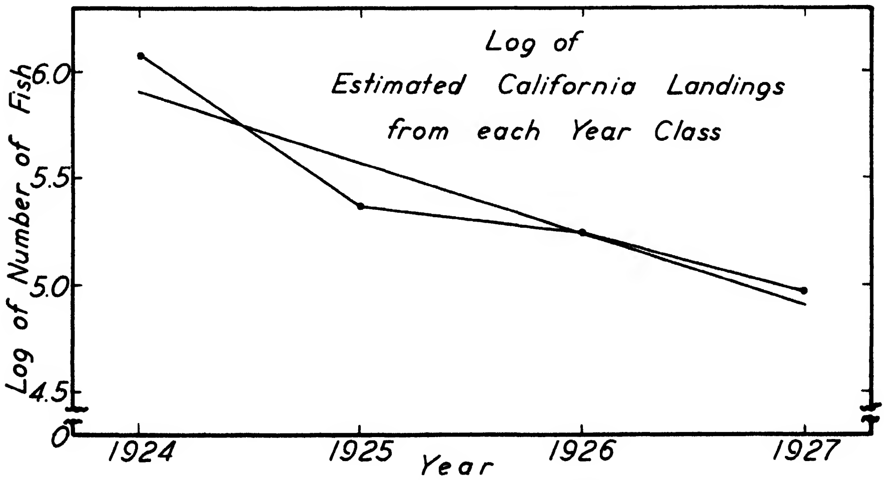

Fig. 5. Semi-logarithmic graph of estimated California landings from each year class, 1924-1928. The year given is the year in which the year class first entered the commercial fishery as group A fish. The straight line graduating these data was fitted by the method of least squares.

vided by the data on total catch and the length-frequency data—and the conclusions reached should only be considered as tentative. Nevertheless, it is hoped that the pattern of this failure of the California fishery has been described in enough detail to make possible the early recognition of a similar failure in albacore fisheries elsewhere.

OREGON ALBACORE

The data for the study of the Oregon fishery have been gathered since 1938, the second season in which substantial landings of albacore were made at Oregon ports. The work during the season of 1938 was chiefly preliminary and of an exploratory nature; but beginning with the season of 1939 a planned program was initiated and is still in progress. The data available for analysis here include chiefly the results of measuring samples of the commercial catch as delivered. A few similar measurements were taken at sea from catches made from separate schools of fish.

METHODS.—In the beginning an attempt was made to measure a sample of 100 fish each day. However, this plan underwent considerable modification during the course of the season because the supply of fish proved, in general, to be too irregular and towards the end of the season too small to permit constant samples of the size desired. In practice, and with 200 as an upper limit, as many fish as possible were measured whenever landings were made and fish were available to the investigator. This practice of course caused the sampling procedure to be influenced by the success or failure of the commercial fishery. However, fishing was generally successful enough so that the original sampling scheme could be followed through the first month or six weeks of the season.

The length of the fish was taken on a measuring board. This board had a vertical stop at one end against which the nose of the fish was placed, and a meter stick embedded lengthwise in the board with the zero end at the vertical stop. The fish were measured by being placed side down along the board on top of the meter stick, nose against stop, and the length to the tips of the middle caudal rays was read to the nearest half centimeter.

Sexing the fish was accomplished by cutting into the visceral cavity and examining the gonads. This method proved to be accurate and reliable for the larger fish, but difficult for fish of less than 60 centimeters in length. These smaller fish were so slightly developed sexually that it was not easy to identify the sexes accurately, and it is probable that some of the females were mistaken for males in these smaller sizes. A microscopical examination of some of the gonads was made to confirm the preliminary sexual identifications. The most obvious gross differences in the gonads of male and female fish are in their shape and color. The ovaries are flesh-colored organs with a ribbed internal cavity throughout their length, while the testes are flattened, whitish-yellow organs, relatively solid.

Milt could be squeezed from the testes of some of the more mature males, but no females were found in which eggs could be discerned by the unaided eye. Measurements of eggs of a number of female fish by means of a micrometer eyepiece in a compound microscope gave a range in diameter of from .01 to .1 mm. This is very much less than the diameter of mature ova of the albacore of the Mediterranean which are reported (Sanzo, 1933) to be from .84 to .94 mm. in diameter.

LENGTH-FREQUENCY DISTRIBUTIONS, 1938-1940.—The detailed data are given in Tables B to E of the Appendix. In 1938 and 1939 and the first part of 1940 the measurements were made in inches but since the last of July, 1940, measurements have been made in centimeters. The measurements in inches were made to the nearest eighth and those in centimeters to the nearest half centimeter. In the tables the lengths in inches have also been given in centimeters for more ready comparison with the later data. The frequency distributions are presented graphically in Figure 6 of which the upper panel relates to the 1938 data, the second panel to those for 1939 and the lower two panels for, respectively, the data for the period July 13-21, 1940, and that for July 30 to October 14, 1940. For most comparisons involving 1940 Oregon data the later period (Fig. 6, panel 1940b) was used, partly because the dates are comparable with those of other years, and partly because the original measurements were made in centimeters.

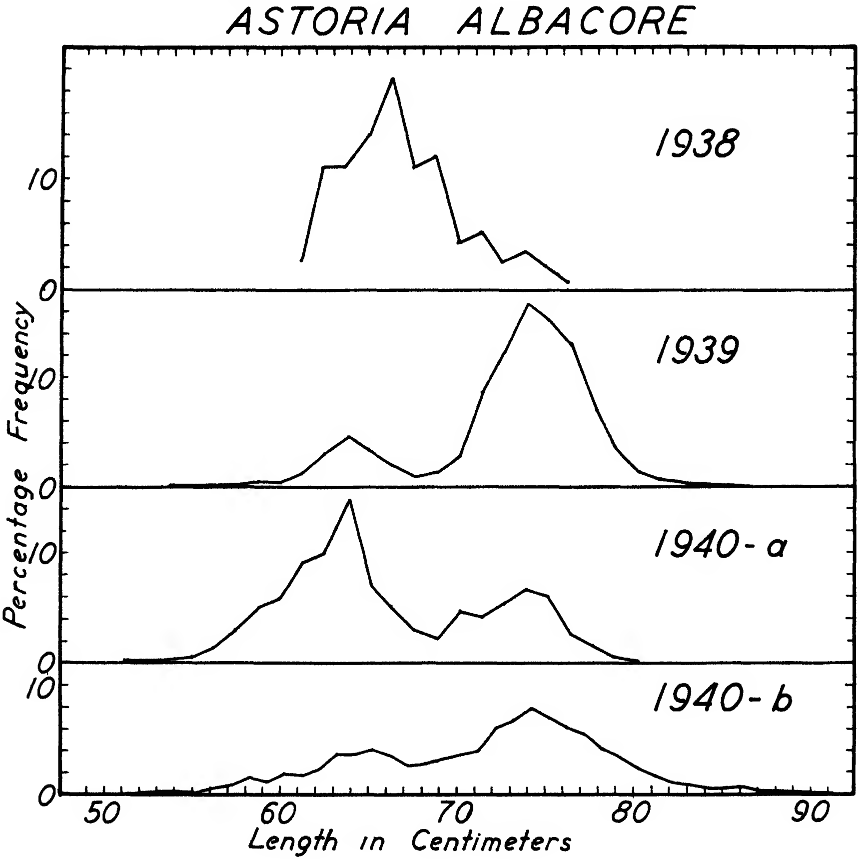

Fig. 6. Length-frequency curves, Astoria albacore, 1938-1940. The measurements for 1938 were all made on a single day. The panel 1940a covers the period July 13 to 21 and the panel 1940b the period July 30 to October 14.

The data for 1938 were all taken on a single day and are too few to fairly represent the fish of that year or to serve as a basis for significant comparisons with the similar data for later seasons. They do show, however, a principal mode at 66 centimeters which agrees fairly well with one of the principal modes in the data for 1939 and 1940. The curve does not show the marked bimodality characteristic of the other years but is strongly skewed toward the larger sizes which may be taken as an indication that one or more older age groups were present although not in sufficient numbers to produce a bi- or multimodal curve.

The sampling in 1939 and 1940 was much more adequate; nearly 3300 fish were measured in each of these years. In 1939 the samples covered the period from August 25 to October 17 and in 1940 from July 13 to October 14. In most respects the length frequencies for 1939 and 1940 are similar. The most marked characteristic is a decided bimodality which indicates strongly that there are only two principal size groups that enter the Oregon fishery. In this respect the Oregon length-frequency distributions bear a close resemblance to those of southern California. (Compare Figs. 2 and 6; but note that the scale of the X-axis in Fig. 6 is twice that of the X-axis in Fig. 2.) This bimodality, therefore, seems to be a constant character of the albacore of the northeastern Pacific and the same terminology will be used in discussing the Oregon data as was used above for the apparently similar groups found in the California fishery, i.e., the smaller of the two modal groups will be designated as group A and the larger group as group B.

The length distribution of group A is skewed toward the lower end. This may be either the result of gear selection, growth, or the presence of one or more minor groups representing, perhaps, younger fish. In 1940, especially, the irregularities below the smaller mode indicate that the entire modal group may be a complex of several minor groups which may not, however, individually represent distinct year classes.

The length distribution of group B is approximately normal except for some slight skewing at the upper end of the curve. This may indicate the existence of a small group of older fish which may be called group C—without, however, intending to imply that it represents a single age or size category.

Inspection of Tables D and E in the Appendix shows that, in 1940, the relative proportion of groups A and B underwent systematic changes during the progress of the season. Group A appeared more abundantly in the landings of the early part of the season and became relatively less abundant as the season progressed, until, during the final portion of the season, very few fish of this group were taken in the fishery. This is shown clearly in the two lower panels of Figure 6.

SEXUAL DIFFERENCES IN LENGTH.—In attempting to analyze length-frequency distributions of the sort available for this study of the albacore it is obviously important to determine the sex, if at all possible, because of the confusion that is certain to result if there are marked sexual differences in size that are not recognized. It is also important to determine the accuracy with which sex may be determined if, as in the case of the albacore, there may be any difficulty in sexing.

In 1940 a brief study was made to determine whether or not there were sex differences in length and, at the same time, the accuracy of sex determination was examined. From this brief study it seemed quite probable that there was no significant difference in length between the sexes, although, in the case of the smaller fish, there was some doubt as to the accuracy of the sex determination. In previous seasons no attempt had been made to sex the fish. On account of the difficulties involved in improving the accuracy of the sexing and, more particularly, the excessive amount of time required to determine sex as a routine procedure, it

seemed undesirable to follow this line of investigation further. The results of the brief study that was made are given in Figure 7.

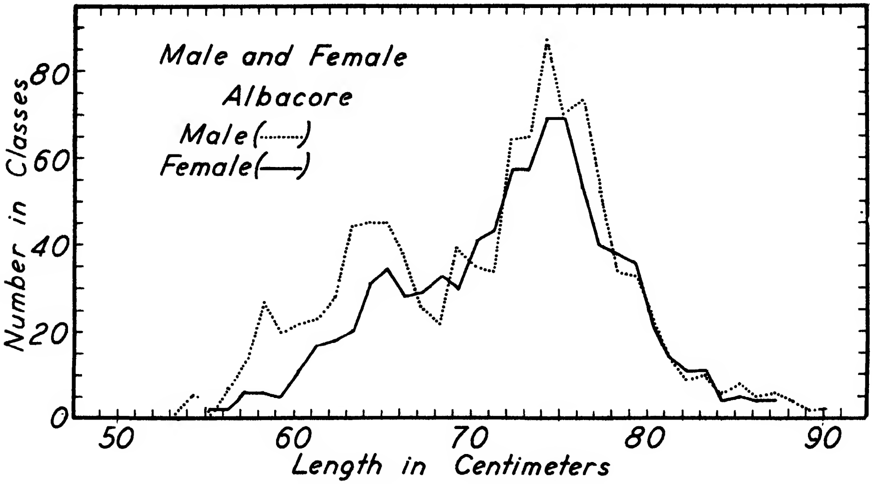

Fig. 7. Length-frequency curves of males and females, Oregon albacore. Only the samples taken from July 30-Oct. 14, 1940 (panel 1940b, Fig. 6), are included.

An examination of Figure 7 will show that males apparently predominate among the fish less than 67 centimeters in length. Chi square was used to test the significances of this disproportion on the hypothesis that the sexes were equal in the population from which the sample was drawn. A similar test was made for the fish 67 centimeters and more in length. The result of the first comparison indicated that the difference in the numbers of male and female fish 66 centimeters and less in length was highly significant ($P<.001$). The second comparison gave a nonsignificant result ($P=.15$). Now it does not appear likely that any difference in proportion of the sexes would disappear with growth so that it is reasonable to think that the significant difference observed between the numbers of males and females in the fish less than 67 centimeters was due to incorrect determination of sex in a significant proportion of these smaller fish. It seems clear that some of the smaller females were wrongly called males.

While the true sex ratio may not be one to one, the result of the second chi-square test is consistent with the hypothesis that the sex ratio is approximately one to one for all fish 67 centimeters and more in length. In view of the evidence that sexing of the smaller fish was inaccurate, further study of possible sex differences was based only on the larger fish in which sexing may be assumed to be accurate.

It may be mentioned that, while a sex ratio other than one to one would have interesting biological implications, this, in itself, would be no obstacle to combining the length frequencies of the sexes for certain other types of analysis. It is entirely possible that, regardless of the sex ratio, the male and female fish may not differ insofar as any particular character such as length is concerned. A chi-square test of the homogeneity of the two comparable length frequencies for males and females above 66 centimeters in length was applied without making any assumptions regarding the relative proportion of the sexes. The ratio method was

used (Simpson and Roe, 1939, p. 303). Chi square was 15.6 with 20 degrees of freedom showing that the difference in the two distributions was not significant ($P=.74$). It may be assumed, then, that the length measurements for the two sexes may properly be combined and regarded as a whole.

SEASONAL CHANGES IN SIZE OF NORTHERN ALBACORE.—With the advance of the season the position of apparently homologous modes in the length-frequency curves of individual samples shifts upward toward the greater lengths. It is as if the fish in the later samples had grown during the season. This effect may be detected by a close comparison of the several modes of the different samples as shown in Figures 8 and 9. Such a shift in the modal position might result from the growth of the fish over the sampling period or, through some unknown cause, the smaller sizes in each group might disappear from the fishing areas or larger sizes might enter. Of course, if the modal groups are not truly homologous through the series, any analysis on the basis employed here becomes meaningless. However, the consistency with which a given mode appears at approximately the same position in samples taken through the season strongly suggests that these modes actually do represent the same groups of fish and that the changes in size represent growth.

In studying these shifts in modal lengths through the seasons of 1939 and 1940 the individual samples have been combined into units of more or less similar size and covering somewhat similar periods of time (Tables C, D, and E, Appendix; and Figs. 8 and 9). The exact combinations used were, of course, strongly conditioned by the number and size of samples available, and their distribution through the fishing season. Histograms were then drawn for each distribution thus provided and the modal groups comprising the distributions were fitted by a number of normal curves. For the 1940 data the goodness of fit of these normal curves to the distribution was tested by chi square. These distributions and the derived histograms and normal curves form the basis of the analysis of the seasonal changes in size.

The method used for identifying and separating homologous groups in this series of frequency curves is an adaptation of a more critical and as yet unpublished method developed by Mr. O. E. Sette of the U.S. Fish and Wildlife Service. Thanks are due Mr. Sette for permission to use this method and for aid in its application. The method involves first the construction of a set of normal curves having different standard deviations and different areas. These curves are placed over the histograms (drawn to the same scale) which are illuminated from below by means of a special tracing box. The standard normal curves that best fit the histogram are selected by eye and then sketched in over the histogram (see Figures 8 and 9). The theoretical class frequencies are then estimated by noting the height of the normal curve at the class centers of the histogram. For the 1940 length frequencies all identical modes, that is, modes representing the same group in samples taken at different times, were, throughout the series, fitted with curves of the same standard deviation. Furthermore, the mode of group B was so fitted that the theoretical modal positions when plotted on a time scale lay on a straight line (Fig. 10). It may be assumed that the slope of this line represents the growth rate in centimeters per day. The differences between the observed length-frequency curves and the combinations of normal curves fitted to them are not significant as tested by chi square ($P=.22$).

The chi-square test was applied in the customary way but the computation of the number of degrees of freedom lost in the curve fitting will be explained.

In the series of six samples studied there were, altogether, 24 curves fitted which were placed into five modal groups. Some of these modal groups were absent from some of the samples, otherwise 30 curves would naturally have been fitted. For each curve the areas of the observed and the theoretical distributions

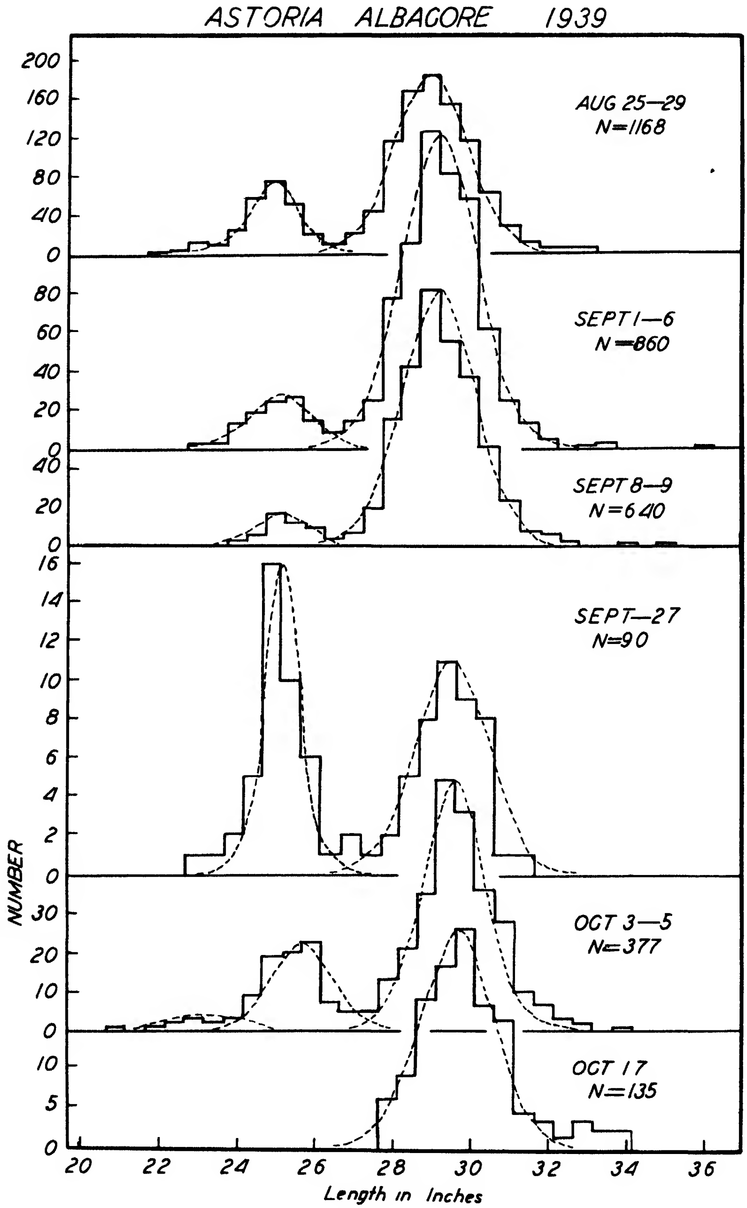

Fig. 8. Length-frequency curves of Astoria albacore for 1939 by groups of samples.

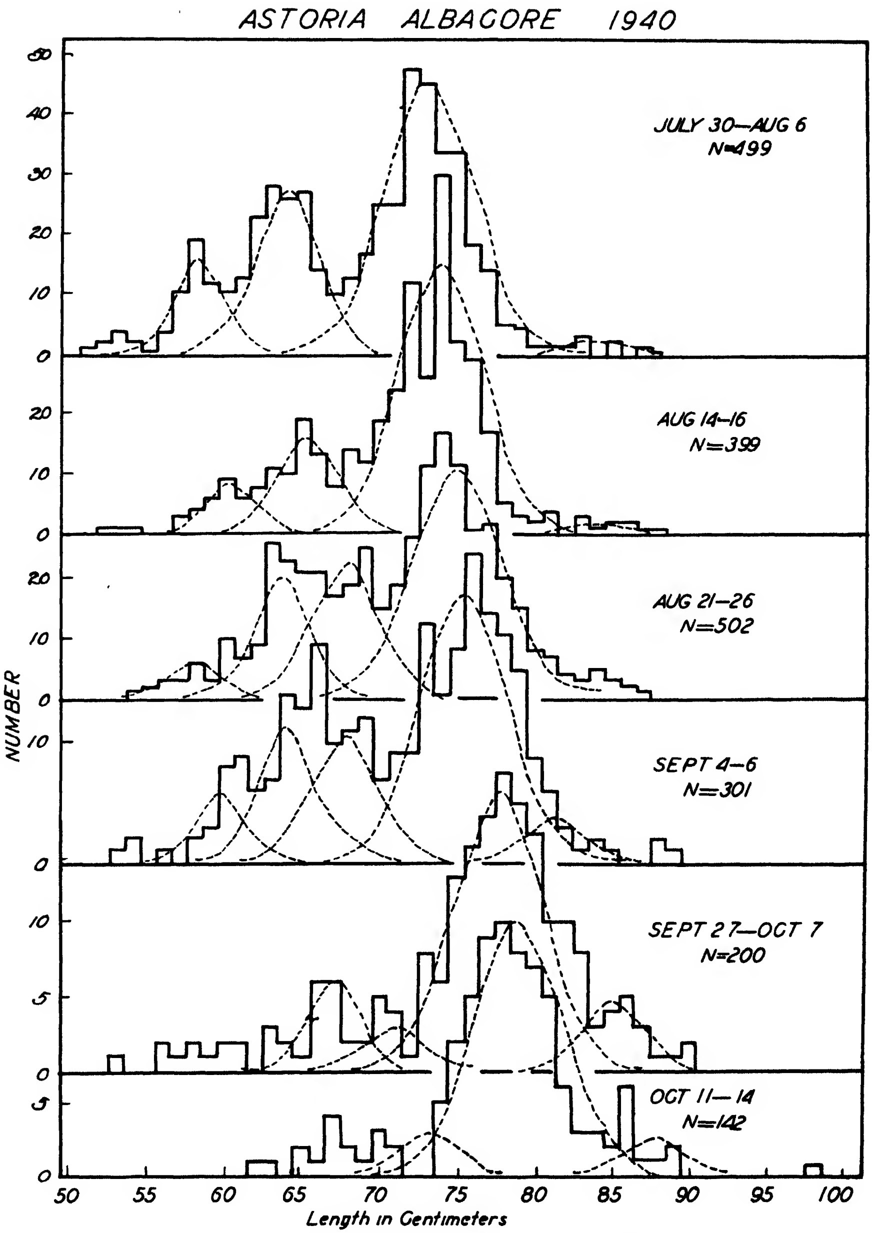

Fig. 9. Length-frequency curves of Astoria albacore for 1940 by groups of samples (panel 1940b, Fig. 6).

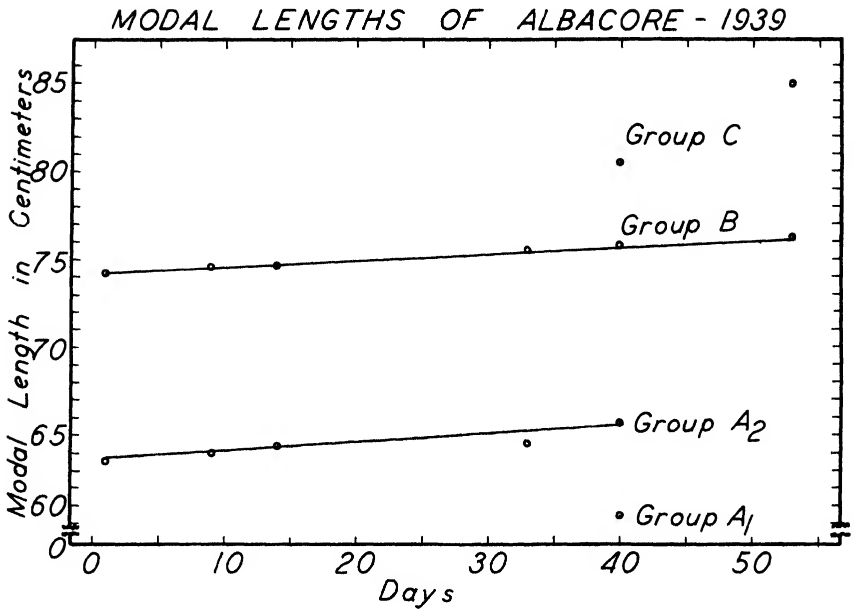

Fig. 10. Modal lengths of Astoria albacore, 1939. The straight lines graduating the modes for groups B and A_2 were fitted by the method of least squares.

were adjusted until approximately equal, causing the loss of 24 degrees of freedom. Each modal group was fitted, wherever it appeared through the series of six samples, with curves of the same standard deviations and this caused the loss of five degrees of freedom, one for each group. The means of the theoretical group B distributions (see Fig. 10) were so adjusted that they fell on a straight line when plotted on a time scale. Since it is only necessary to fix two points to define a line, two degrees of freedom were lost in fitting these means. However, the means of the remainder of the curves were adjusted so as to give the best fit. Since there were 18 such curves, 18 degrees of freedom were lost. And lastly, six degrees of freedom were considered lost for the liberty of varying the number of curves fitted for the different samples. The degrees of freedom considered lost through this procedure of curve fitting are given in the following tabulation:

Areas	24
Standard deviations	5
Means	20
Number of samples	6
Total number lost	55

There were 114 degrees of freedom available altogether, leaving 59 after subtracting those lost in fitting. The value of chi square was 73.73, which for 59 degrees of freedom is, as previously mentioned, nonsignificant (P=.22).

The modal positions, as found by these methods, are given in Table 5 and are shown in Figures 10 and 11. The modal lengths of groups considered to be identical

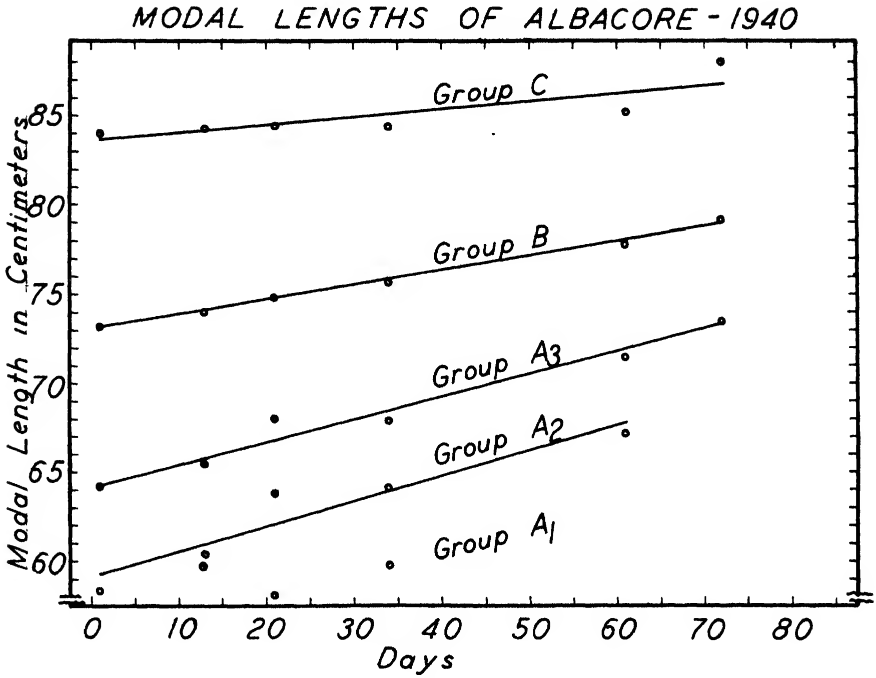

Fig. 11. Modal lengths of Astoria albacore, July 30-Oct. 14, 1940. The graduating straight lines were fitted by least squares.

Table 5. Modal length (in centimeters) of Oregon albacore

Dates	Group A_1	Group A_2	Group A_3	Group B	Group C	Group ?
Season of 1939						
8/25-29		63.57		74.23		
9/1-6		64.07		74.62		
9/8-9		64.32		74.62		
9/27		64.58		75.50		
10/3-5	59.38	65.73		75.76	80.58	
10/17				76.01	84.90	
Season of 1940b						
7/30-8/6		58.45	64.25	73.25	84.05	
8/14-16		60.45	65.45	74.05	84.35	
8/21-23	58.15	63.85	68.15	74.95	84.55	
9/4-6	59.85	64.15	67.95	75.75	84.45	81.75
9/27-10/7		67.25	71.45	77.85	85.25	
10/11-14			73.45	79.15	88.05	

increased with the advance of the season in a fairly linear fashion. On the assumption that growth may be linear, or nearly so, during the relatively short span of the fishing season, an attempt was made to fit normal curves to the data in such a manner that all modes of comparable curves would fall on a straight line when plotted against time. With this method, however, the discrepancy between the theoretical curves and the observed data was too great (as tested by chi square) to be attributed to chance, except for group B in 1940 as mentioned above. The discrepancies observed in the other modal groups indicate that departures of some of the modes from straight lines fitted to them might be significant of real differences among groups thought to be identical and the question arises as to whether the series of modes do actually represent identical groups in the different samples. However, these discrepancies, although statistically significant, are so small it seems unlikely that they could be caused by grouping together fish actually belonging to different year classes. It seems more likely that a given year group contains sub-groups of fish derived from various sources and that the fish of the same age group in different schools contain varying proportions of these sub-groups and so have different modal lengths. Some evidence of the existence of such differences among different schools of fish is given below (page 224). It is shown there that fish from different schools may have quite different ranges in length. While these differences seem to result more from the varying porportions of groups in different schools than in differences in the modal lengths of the individual groups themselves, it is quite possible that the modal lengths do vary erratically and significantly from school to school. If this be true then, unless the same admixture of schools were represented in the commercial catch throughout the season, it may be impossible to obtain statistically satisfactory fits between the observed positions of the modes of all groups through the season and the theoretical position calculated from a corresponding series of growth lines. Furthermore, any attempt to force the fit of the modal position of a major group to a growth line as has been done successfully for group B for 1940, may force the displacement of other minor groups in order to achieve a nonsignificant chi-square value. The problem involves in part the unraveling of the admixture of schools inevitably present in the samples but this is a difficult and complex matter which has not been attempted for this report.

The discrepancies between the observed modes estimated from an assumed linear growth rate may be the result of the sampling procedure. The date on which the sample was actually measured has been employed here in plotting the modal positions. However, almost all of the fish measured were from troll catches and, because of the duration of the fishing trips, the delay between capture of the fish and sampling could vary as much as a week. Growth stopped, of course, at the moment of capture and, with such a rapidly growing fish as the albacore, an error of several days in locating the sample on the time scale might well contribute to the observed eccentricities in the modal positions of groups from sample to sample.

As stated above, with the exception of group B for 1940, it has been impossible satisfactorily to fit any of the series of length-frequency distributions with normal curves the modes of which fall on a straight line. It was, however, possible to fit all of the 1940 length-frequency distributions with normal curves which, for each series, had the same standard deviation. This may fairly be taken as an indication that the groups of the various samples were correctly identified.

No attempt has been made to apply the chi-square test to the fit of normal curves to the 1939 series data as was done with the length-frequency data for 1940. It was felt that the data for 1939 did not allow fits of as high a degree of accuracy as did those for 1940 and that, in all probability, fitting normal curves

carefully by eye would provide as close an approximation to the true modal positions as was useful. In Figures 8 and 9 the observed data for 1939 and 1940 are shown as histograms on which have been superimposed the fitted normal curves.

The growth rates as shown by the progression of the modes during the season have been calculated in terms of centimeters per 30 days and are given for 1939 and 1940 and for the two major modal groups in Table 6. It is recognized, of course, that the change in the position of these modes may not be due entirely to growth but it is believed that growth is the major factor responsible for these changes, and for this reason the term "growth rate" was used. It is clear from the table that the growth rate was higher for both groups in 1940 than in 1939 and that, in both years, the growth rate was higher for group A than for group B. Furthermore, the rate is so high that, if continued for a year, it would cause differences between adjacent modal groups far greater than those observed. This means, in all probability, that the growth rate is much lower during the winter months than during the period covered by the Oregon fishery. Such a condition would not be at all unusual—an annual cycle of growth has been described for many organisms, including fishes (Rich, 1925), and a similar pattern probably occurs for the majority of temperate cold-blooded vertebrates.

Table 6. Albacore growth rate in centimeters per 30 days

Year	Modal Group A	Modal Group B
1939	1.38	1.07
1940	4.00[1]	2.44

[1]This is an average of two minor groups.

Group A, especially for 1940 (Fig. 9), appeared to be a mixture of several minor groups. The fact that several normal curves were required to fit satisfactorily the length distributions of this group as a whole (Fig. 9) would indicate its complexity; nevertheless it was regarded as a single year class for reasons that will be given later. There were at least three minor groups present in 1940 which, starting with that made up of the smallest fish, were designated A_1, A_2, and A_3 (Fig. 11 and Table 5).

The growth rate of the minor groups making up group A for 1940 was exceedingly high (see below). Minor group A_1 (Fig. 11) was not sufficiently well represented to show its growth rate. However, group A_2 reached a modal length substantially greater at the season's end than group A_3 possessed at its beginning. The growth rate of A_2 was likewise more rapid than that of A_3, reducing the difference between the two groups by about half during the season. This seems clearly to indicate that these minor modal groups were not separate year classes. Such minor groups may have arisen from a succession of spawning maxima through the spawning season, or may each represent the contribution to the stock of several spawning or nursery grounds.

As shown by Table 6, the growth rate during 1940 was more than twice as great for comparable groups as it was for 1939. Recalling the uniformity of growth between group A of one year and group B of the next as exhibited by the California data, this fact casts some doubt on the assumption that growth is entirely responsible for the observed changes in size. Something that simulates growth as measured by the method employed here may be responsible, and it may be necessary to resort to such techniques as measuring fish that had been previously measured, tagged, and released to determine if such be the case.

It has been mentioned above that the fish of group A would normally exceed those of group B in absolute abundance in the sea even though the former may be less abundant on any given fishing ground at any given time. However, it was shown in the section on the California fishery that the fish of group A were consistently fewer than the fish of group B in the landings as sampled. Since the fish of group A average smaller than those of group B it follows that there is an even greater difference in the weight of landings than in the number of fish of the two groups.

A similar condition characterized the Oregon fishery during the major portions of the seasons under consideration here, 1938 to 1940. For a few weeks quite early in the season there is a tendency for the fish of group A to dominate the catch but the remainder of each of the three seasons is strongly dominated by group B. It may be noted here, however, that group A dominated the catch throughout the season of 1941—a reversal of the condition noted in the three previous seasons. The rapidly growing fish of group A of 1940 apparently did not enter the fishery as group B in 1941 in the abundance that would have been expected on the basis of the experience of the preceding three years.

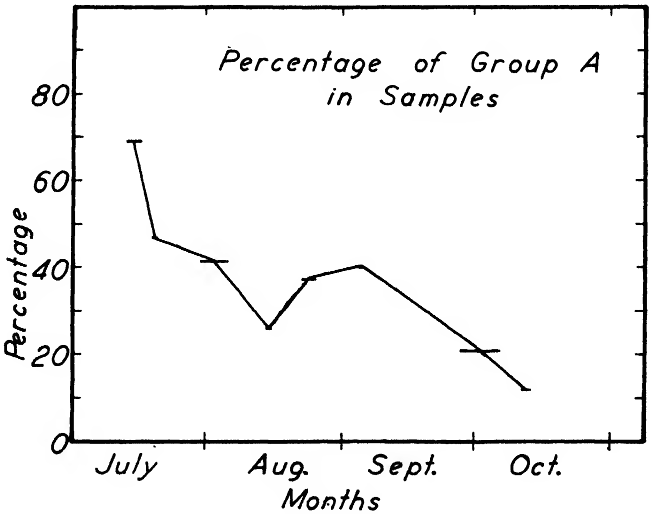

Fig. 12. Percentages of albacore of group A in the samples taken from the Oregon catch for July 30—Oct. 14, 1940.

There is no obvious correlation between these percentages (Fig. 12) and the monthly landings which were as follows: July, 2,589,000 pounds; August, 5,233,000 pounds; September, 1,320,000 pounds; October, 144,000 pounds. It is to be noted however that October (and to a lesser degree September also) is characterized both by small and irregular catches and by a relatively small percentage of fish of group A in the landings. Group A would seem, then, to appear in abundance on the fishing grounds earlier and likewise to leave first. This may be an indication that the two groups tend to school separately and to have different distributions on the fishing grounds. Such a situation would obviously have a disturbing effect on any sampling program for the fishery because the time and place in which fishing was

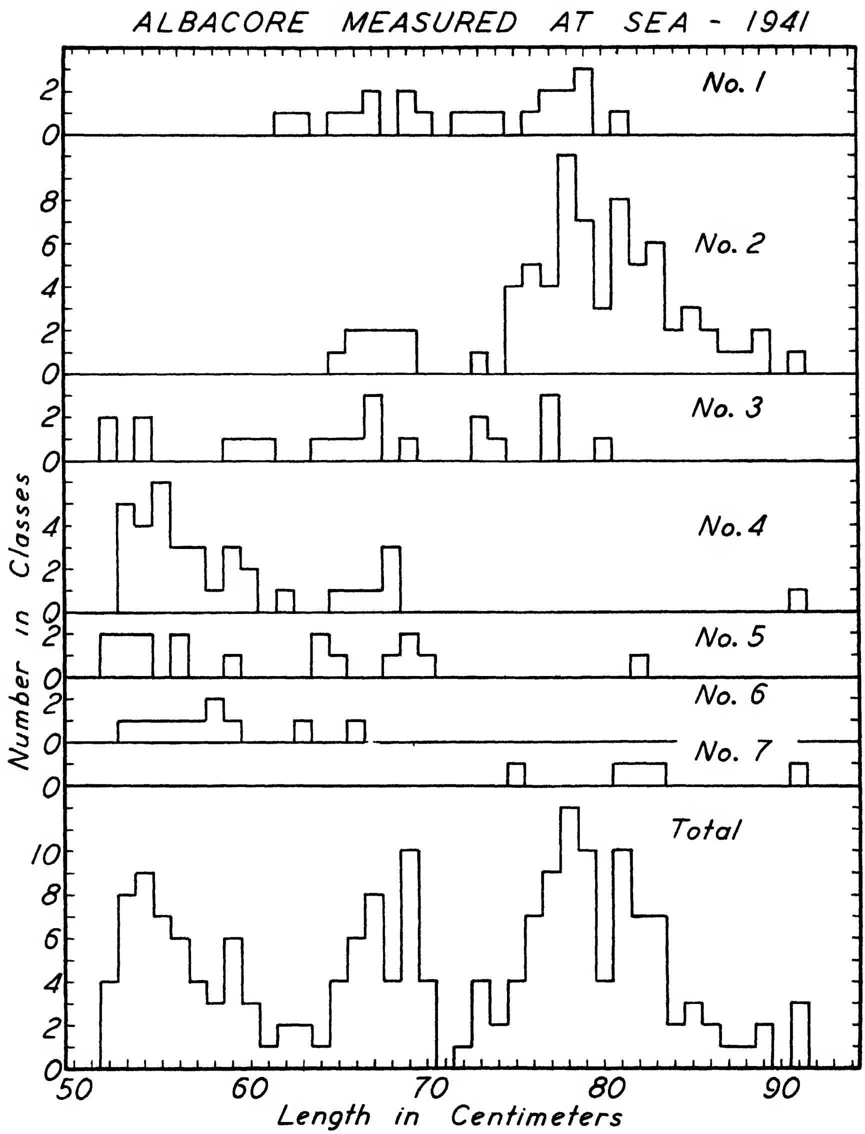

Fig. 13. Length-frequency histograms of Oregon albacore measured at sea, 1941, by individual samples.

concentrated could have an important effect on the relative numbers of A and B fish landed. During the season of 1941 an attempt was made to determine the differences among schools of albacore by measuring samples of fish landed aboard individual live-bait boats. These measurements were made at sea as the fish were caught during the normal course of fishing and the fish taken at a given spot during the course of continuous fishing were assumed to be from a single school. Seven such samples were obtained, each presumably representing a school. The length-frequency histograms are shown in Figure 13. An analysis of the variance of the samples of this series was made by the method of Snedecor (1934). This shows that most of the variance could be assigned to variation between samples rather than to variation within samples. Tests of the significance of the result gave a low probability ($P<.01$) that the difference between schools was due only to chance.

It is quite possible that this is the usual condition in schools of pelagic fishes such as the albacore. Serventy (1941) indicates that immature southern bluefin tunny (up to the fourth year of age) school separately from mature fish. He shows, in fact, that the range of the two is quite different. Kishinouye (1923) indicates for the Japanese fishery that schools of immature or small fish of both the bluefin and yellowfin tunas are to be found at other places and times than are the schools of larger and probably mature individuals. However, neither of these authors give any evidence to indicate that fish of similar size school together and are distinct from schools of fish of other sizes on the same fishing grounds at the same time. The latter, as shown by the analysis of variance, seems to be true of the schools of albacore found off the Oregon coast.

A more complete discussion of the interesting data shown in Figure 13 must be reserved for a future paper that will treat more fully the fishery of 1941. The significance of the clear-cut trimodality shown in the lower panel ("total") can not be understood without comparing these data with others derived from the larger routine samples of the commercial catch for that year.

COMPARISON OF CALIFORNIA AND OREGON ALBACORE

A comparison of the characteristics of the albacore samples taken in California between the years 1924 and 1928 with the Oregon samples representing two of the years studied (Figs. 2, 8, and 9) shows the essential similarity between the two series of data. Both length-frequency distributions are of much the same form and, in all probability, the same age groups are present in both. On the whole, however, the California modal lengths are a little greater than the corresponding ones for Oregon, and the difference between the mode of group A in one year and that of group B in the next year is likewise a little more. However, the two sets of data are not strictly comparable because of the different methods used in measuring the fish. The California albacore were measured by stretching a tape over the body of the fish, while the Oregon albacore measurements, as previously described, were made by placing the fish on a measuring board. Nevertheless, a significant difference remains even after converting the California lengths to the equivalent of the Oregon ones by the use of a suitable factor. This factor was determined by measuring a sample of fifty albacore by both methods. The two series of lengths for the same fish were fitted to a straight line by the method of least squares and it was found that measurements made by tape may be converted to the equivalent of measurements made by measuring board by multiplying by the factor 0.953. Conversely a factor of 1.049 will make the opposite transformation—that of measuring-board lengths to the equivalent of measurements by tape over the body. The data are presented in Table 7.

Table 7. Modal length of California and Oregon albacore (in centimeters)
(Measuring-board basis)

Group A	Group B	Difference
California albacore (1924 to 1928)		
1924 - 64.89	1925 - 77.18	12.29
1925 - 64.87	1926 - 77.16	13.29
1926 - 68.84	1927 - 81.04	12.20
1927 - 65.80	1928 - 78.27	12.47
Oregon albacore (1938 to 1940)		
1938 - 66.18[1]	1939 - 74.19	8.01
1939 - 64.02	1940 - 74.26	10.24

[1]Only a single small sample was taken in 1938 after the season was under way.

In the California series the difference in length between group A of one year and group B of the year following varied from 12.2 to 13.3 centimeters (Table 7). In the Oregon samples the difference at approximately the same dates between the length of group A in 1939 and group B in 1940 varies from 11.1 to 11.85 centimeters depending upon which portion of the season is compared. The Oregon samples, although a year apart, were taken on approximately the same dates so that a fair comparison could be made of the lengths of A and B fish at different times during the season.

As described above, the positions of the modes in the Oregon data were determined by a somewhat different method from that used for the California data (see pp. 204 and 215). If the Oregon modal positions be determined by the same method used in the case of the California length-frequency distributions (that of averaging the five highest classes in the seasonal summaries near where the mode is suspected to lie) the observed difference in the amount of growth between Oregon and California fish is somewhat increased. However, the particular method employed for estimating the modal positions from the Oregon length distributions may be responsible in part for this apparently increased divergence in growth between Oregon and California fish. Over 68 per cent of the data on length distribution for 1940 was obtained at an earlier date in that season than the beginning of the season of 1939 (see Tables C and E in Appendix). The growth found by comparing fish measured in a late season to those measured in an early season following, employing seasonal summaries, would be less than that found by using measurements obtained a full year apart. These Oregon modes together with the California ones, on a comparable measuring-board basis, are shown in Table 7.

Nevertheless, the growth experienced by the California fish was greater than that of the Oregon fish as shown by estimates not based on seasonal summaries of the measurements for Oregon. The growth as shown by differences between groups A and B were, as mentioned above, 11.1-11.85 centimeters, which are .35-2.20 centimeters less than that estimated for the California fish. Hence, the lesser growth for Oregon fish as shown in Table 7 is doubtless not all due to the method used in estimating the modal positions there. Apparently that lesser growth was due not to a difference in the position of group A in Oregon and California but to a difference in the position of group B (see Tables 5 and 7). Modal points for group A in Oregon and California do not differ to any significant extent; but the modal points for group B of Oregon seem to be consistently less than those of California. This

may indicate that the growth rate of the northern populations is less rapid or that the season of rapid growth is shorter.

It is quite possible that other causes may be responsible for these differences. For one, the fishing methods employed in Oregon and California are distinctly different, at least for the period included in this study. The California fishery was one largely dependent upon the use of live bait for the capture of fish, while the Oregon fishermen have depended, in the main, upon trolling with artificial lures for their catch. It is conceivable that the two fishing techniques would tend to take, on the average, fish of different sizes.

In spite of observed differences it appears likely that on the whole a similar biological situation exists today in the Oregon albacore fishery to that which formerly existed in the California fishery. Certain differences have been shown to exist in the two populations, but those differences are essentially minor and matters of detail. The two fisheries present an essentially similar picture. This favors the hypothesis that the segment of the albacore population now exploited in Oregon represents a similar portion of the common stock to that previously exploited in California and that the range of these fish covers both fishing grounds. The fact that the periods covered by the data from each of these two fisheries are separated by about 10 years indicates further that the portion of the albacore population involved has not altered greatly during the interim.

If these tentative conclusions be accepted, certain other conclusions follow regarding the present state of the fishery, unless other and more complex assumptions be made regarding the albacore populations in southern California. For example, if the Oregon and California albacore populations are, at present, identical, albacore data collected in Oregon should resemble that taken in California. There are, unfortunately, no data on the California fish that are available to the writer on which to base such a comparison; but an attempt has been made to learn something through an analysis of the duration and time of the fishing season for the various Pacific Coast albacore ports. Such an analysis will not serve as a rigorous proof of the identity or nonidentity of the populations involved but it may serve to clarify the situation and does have interesting connotations in respect of other points.

Table 8 gives the monthly landings in percentage frequencies for the important albacore ports on the Pacific Coast of North America. These data are for landings made during the entire period from 1936 to 1940.

Table 8. Percentages of total landings of albacore by months for each major port, 1936-1940

Port	June	July	August	September	October	November	Percentage of total
San Diego..........	29.7	24.8	30.2	1.4	5.5	8.4	2.0
Los Angeles........	7.6	33.5	34.6	12.8	8.9	2.6	12.6
Santa Barbara......		.5	9.6	55.8	32.7	.4	6.7
Monterey...........		.1	16.5	61.3	22.1	.1	19.7
San Francisco......			1.0	96.1	2.9		1.2
Astoria[1]...........		15.2	47.6	30.2	6.8	.2	57.8
							100.0

[1]Landings made by boats in Californian ports from northern waters are not included in these percentages.

It will be noted that south of San Francisco there seems to be a tendency for the season to be both later and shorter than for the more northerly ports; however, the landings at Astoria are not in harmony with this trend. The July landings at Astoria constituted over 15 per cent of the total while the landings during this month were less than 1 per cent of the total for any California port north of Los Angeles. Similarly, August is the month of heaviest landing at Astoria while September is the best month at Santa Barbara.

During the month of August albacore are present along the Pacific Coast from San Diego north to, in one year at least, Cape St. James (Lat. 52°40' N.) at the southern end of the Queen Charlotte group (Sampson, 1940). This month has been best, on the average, of all months of the fishing season for both Astoria and Los Angeles, which would indicate that the heaviest runs of the season were present at both of these two widely separated ports at the same time.

This would argue that the schools of fish off the Oregon coast were not a part of the schools appearing off the California coast, even though, as indicated above, the two groups may have had a common origin. It is to be noted that such data as these would have little bearing on the question of the common origin of the two groups. The time of arrival of fish and their abundance as shown by the monthly commercial catch for the ports discussed here make it seem likely that at least two separate groups of schools invaded the coastal area, one in the north off Oregon and the other in the south off southern California. Hence, it appears not unlikely that the movements of fish to the fishing areas are not along the coast but are, instead, movements predominantly toward and away from the coast. There may be, of course, local movements parallel to the shore after the fish have reached the coast; but the chief movement seems to be at right angles to it. Local coastwise movements north and south may exist in the region from San Diego north to Santa Barbara and may even include the fish landed at Monterey and San Francisco. It may be suggested that these fish landed in central California may represent an independent group of schools, or they may even be derived from the northern runs.

In the preceding discussion, the distribution, size, and fluctuations in activity of the fishing fleets have not been considered. This is due, in part, to lack of satisfactory data and in part to a conviction that the abundance of fish has been of more importance in determining the size of the catch. This assumption is justified by the fact that the demand for albacore has generally exceeded the supply with the possible exception of the first one or two seasons of fishing at Astoria. Hence, it is likely that the mean annual catch would reflect, in the main, the availability of the fish to the fishermen. The mean annual landings at the chief ports are shown in Figure 14. These data can not, of course, truly reflect availability for those ports that have no local albacore fishing fleet and where no consistent effort is made to fish this species. For instance, it is shown in Figure 14 that no landings are recorded for the coast between Monterey and Santa Barbara but, because of the absence of any important fishing ports along this part of the coast it is probable that, even if fish were there in abundance, there would be little or no evidence of this shown by the amounts landed. Other fishing methods than those employed at present or the use of present methods in areas not now exploited, or both, might change the situation as described here. It is clear, however, that the average annual Oregon catch from 1937 to 1940 was greater than the combined average annual catch for all ports south of Oregon in spite of the fact that the Oregon fishery was initiated during this period. The total catch in Oregon during the entire period was approximately 25 million pounds while that landed at ports south of Oregon was only about 18 million pounds. In these figures the landings at California ports by boats that fished off the Oregon coast have not been

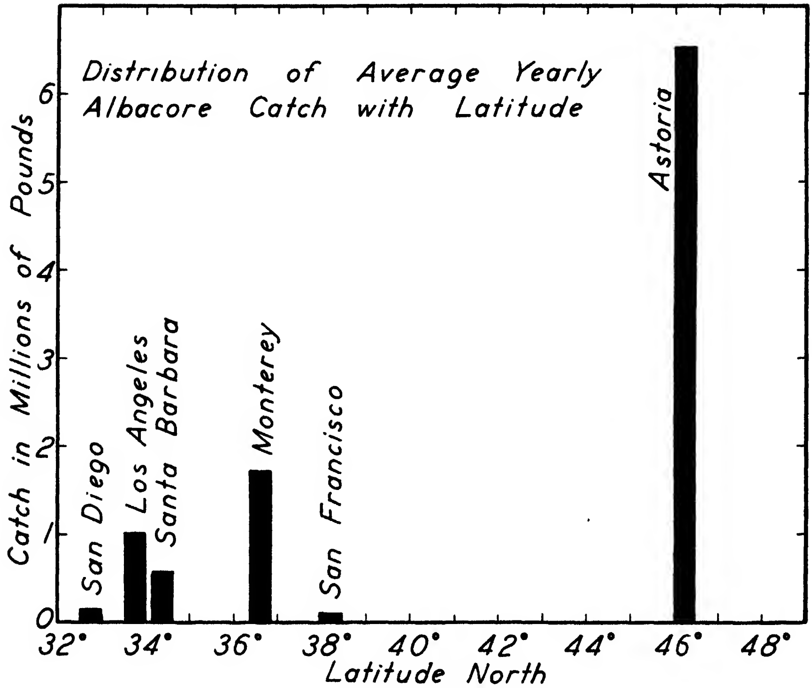

Fig. 14. Distribution in latitude of the mean annual albacore catch along the Pacific Coast of North America. The catches for all ports south of latitude 40°N. were averaged for the years 1936-1940 inclusive. The Astoria catches cover the period 1937-1941 inclusive. Catches made in northern waters and landed in the states of Washington and California, or in the province of British Columbia, are not included.

included in the Oregon totals and the same is true of landings made north of Oregon in Washington and British Columbia. These facts argue strongly that the abundance of albacore has been greatest in the north and also provides additional evidence that the northern and southern groups of fish are independent.

JAPANESE ALBACORE
1935-1936

It has been shown above that, for those years for which data have been available, the albacore catch on the West Coast of North America has, in the main, contained only two year classes. According to the published reports (Uno, 1936a; 1936b) the other main albacore fishery in the North Pacific, that of Japan, seems to draw upon three year classes, of which one is strongly dominant. Uno reports that in the fishing off Nozima Promontory, for example, 91 per cent of the landings belonged to a single year class. The year classes were identified by the use of

"age rings" in the vertebrae and Uno gives the age of the most abundant group as five years. The mean length of this group varies in different samples from 79 to 81 centimeters. The published length-frequency data which are here presented in Table F of the Appendix and graphically in Figure 15 do not confirm either the existence of, or the modal position of, these year classes in the proportions estimated by Uno. However, the majority of the fish lie between the limits of 71 and 89 centimeters, a range of 18 centimeters, which makes it seem probable that only a few year classes were available if American length frequencies may be used as a criterion. This range is, in fact, less than that of the American fish.

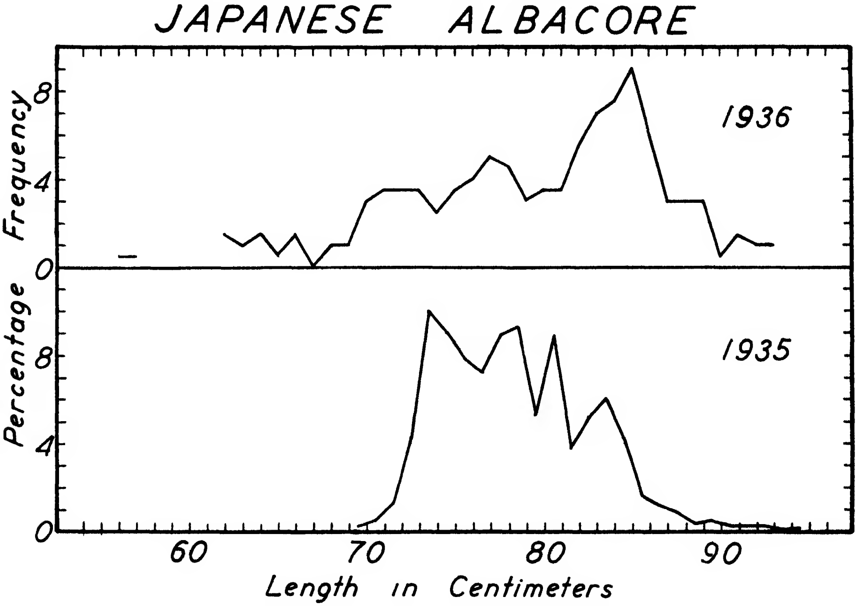

Fig. 15. Length-frequency curves, Japanese albacore, 1935 and 1936, modified from Uno, 1936a; 1936b.

The modes present in the Japanese length-frequency curve for 1935 are, compared with the Oregon and California data, poorly defined and close together. It would be quite impossible to fit this length-frequency curve with a series of normal curves the standard deviations of which were similar to those used for fitting the Oregon data. It may be inferred that either the growth rate of the fish taken in the Japanese fishery is far less rapid than that of the Oregon albacore or else the sampling program of the Japanese investigator was such that fairly large samples were taken at infrequent intervals. Such a sampling technique, if the growth rate were high, might well lead to a seasonal curve that would not clearly show any well-defined modal groups even though the individual samples may have done so.

During the season of 1936, 200 Japanese fish were measured between the first and ninth of June. The length-frequency histogram of these fish shows three fairly well-defined modes, and the groups represented by these modes can be fitted quite accurately between the limits of 67 and 89 centimeters by three normal curves. A

slightly different method was used than that described above for the Oregon fish (p. 215). These fits were first made by eye by sketching three normal curves over the histogram of the length frequency, and then the means, curve areas, and standard deviations of the three groups were estimated from these three normal curves. Then, using the estimated means, curve areas, and standard deviations for each of the three modal groups, three normal histograms were calculated with the same classes and class limits as the histogram of the Japanese length-frequency curve. The three primary constants for the three normal distributions used were as follows: (1) Number (N)-31.4, Mean (M)=71.25, and Standard Deviation (SD)=1.89; (2) N=46, M=76.7, and SD-1.89; and (3) N-92.2, M=84.2, and SD-2.21. The three individual histograms overlapped, of course, due to the proximity of the means of the normal curves from which the histograms were derived and the range of the curves. From these overlapping curves a total curve was derived by addition of the component elements and this combined histogram was compared with the empirical distribution by means of the chi-square test. The theoretical curve with its component elements and the observed distribution are given in Table 9. The theoretical and observed distributions are shown graphically as frequency polygons in Figure 16. As tested by chi square the fit is exceptionally good; the probability (P) that the differences between the two curves are due to "the errors of random sampling" is .95.

Table 9. Observed and theoretical frequency distributions, Japanese albacore, 1936

(Add 0.05 cm. to the values in the left-hand column for true values.)

Length in centimeters	Theoretical frequencies				Observed
	Curve 1	Curve 2	Curve 3	Total	
67	0.7			0.7	0
68	1.6			1.6	2
69	3.2			3.2	2
70	5.3			5.3	6
71	6.5	0.1		6.6	7
72	6.1	0.5		6.6	7
73	4.3	1.5		5.8	7
74	2.3	3.6		5.9	5
75	1.0	6.6		7.6	7
76	0.6	8.8		9.4	8
77		9.5		9.5	8
78		7.6	0.3	7.9	9
79		4.7	1.3	6.0	6
80		2.2	2.8	5.0	7
81		0.8	5.9	6.7	7
82		0.2	10.1	10.3	11
83			14.1	14.1	14
84			16.7	16.7	15
85			15.4	15.4	18
86			11.8	11.8	12
87			7.5	7.5	6
88			3.9	3.9	6
89			1.1	1.1	6
90			0.6	0.6	1
91			0.1	0.1	0

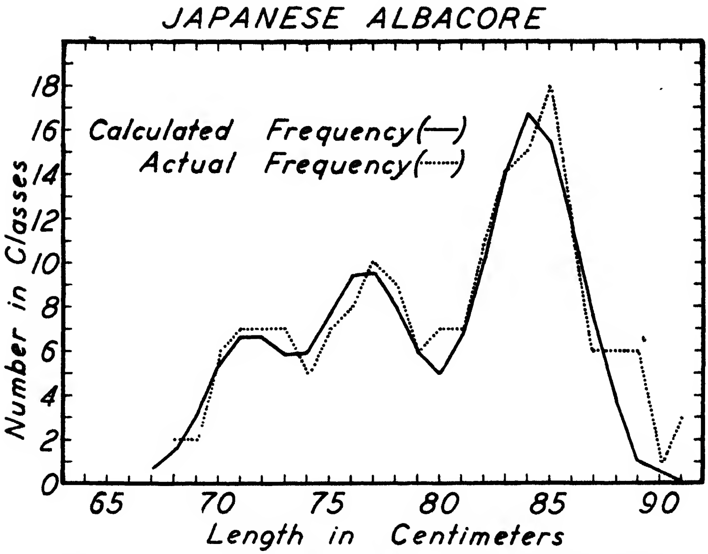

Fig. 16. Observed and theoretical length frequencies of Japanese albacore samples for 1936. The extreme values are omitted.

Assuming that these fish were measured by a tape over the body, the group of fish centering about the highest mode is apparently comparable to group B of the California albacore fishery. This group (Table 2) had a range in modal lengths of 80.3 to 85.0 centimeters which is to be compared to a modal length of 84.2 centimeters for the Japanese albacore. The group of fish centering about the lowest mode at 71.25 centimeters may be compared likewise to group A in the California fishery which had a range in modal lengths of 68.1 to 72.2 centimeters. The middle group of the three in the Japanese length frequencies apparently has no counterpart in the modal groups found in the California length frequencies. It is possible, however, that it is actually a part, as far as age is concerned, of the shorter group. The difference between the estimated mean of this middle group and the estimated mean of the group above is 7.5 centimeters while it differs from the group below by only 5.5 centimeters. If it be assumed that three successive year classes are represented by the three modes, this fact would imply that, as far as this particular sample is concerned, the fish of the oldest group had grown at a more rapid rate than did those of the middle group, which would be a most unusual situation. Furthermore, the appearance of these three modal groups is much like the modal groups occurring in the Oregon albacore fishery (compare Fig. 9 with Fig. 15) and the groups present in the Japanese length-frequency curves may reasonably be given the same interpretation as that given to those present in the Oregon 1940 length-frequency curves; namely that the two lower modes represent distinct parts of a single year class while the highest mode represents another year class. If this interpretation be correct there is apparently a close parallel between the Oregon and Japanese length frequencies with the difference that the modes are somewhat higher for the corresponding Japanese groups.

Uno (1936b) makes no mention of the method employed in measuring these fish.

However, if the assumption is made that the measuring was by means of a tape rather than by a measuring board, the modal lengths must be transformed into the equivalent of measuring-board length if a comparison is to be made (for method see p. 224). When thus transformed the modal lengths of the Japanese albacore are 68.0 centimeters for the lowest group, 73.1 centimeters for the next, and 80.2 centimeters for the highest group. These values are somewhat higher than the corresponding ones for the Oregon albacore, the precise amount depending upon the portion of the Oregon fishing season utilized for the comparison (see Table 10).

Table 10. Comparison of modes of Japanese albacore with those of Oregon albacore taken in 1940 (modal lengths in centimeters)

Japanese modes	Oregon groups	Oregon modes in 1940			
		7/30-8/6	8/21-8/23	9/27-10/7	10/11-10/14
68.0	A_2	58.45	63.85	67.25	.....
73.1	A_3	64.25	68.15	71.45	73.45
80.2	B	73.25	74.95	77.85	79.15

If it be assumed that the Japanese measurements were made originally by means of a measuring board it is difficult to find corresponding modal groups that match in the Japanese and Oregon length frequencies. Similarly, when the modal groups are converted to the equivalent of measurements by tape, assuming that they were made on a measuring board, it is difficult to locate corresponding groups in the Japanese and California length frequencies. It is obvious that the incompleteness of the Japanese data will not permit a satisfactory comparison to be made of the Japanese modal groups with those represented in the California and Oregon fisheries.

A comparison of the group means and standard deviations as found by the method of curve fitting used here and those found by the use of "age rings" in the vertebrae as employed by the Japanese investigators is of interest. Table 11 presents the data relative to the three major groups described by Uno (1936b) from a sample of 688 fish of which those discussed above form a part.

The values given in Table 11 differ widely from the corresponding values for the normal curves that have been fitted to the sample of 200 fish taken early in the fishing season (see above, p. 231). It is remotely possible that this difference may have arisen through differences in sampling, since the age readings shown in Table 11 were determined from 688 fish while the length-frequency curve was based on only 200 of the 688 fish. Further, the 200 were sampled at the beginning of the fishing season while the entire sample was presumably spread over the entire season. The size of Uno's four and five year fish is in fair agreement with

Table 11. Statistics of three major groups of Japanese albacore, given in centimeters. From Uno, 1936b

Age in years	Mean length	Standard deviation	Estimated growth between age groups
4	69.04	4.65	
5	81.56	3.82	12.52
6	89.70	1.98	8.14

that shown by the California fish of groups A and B (Tables 11 and 2); the mean lengths are within the range in lengths of modes A and B in the California fishery.

It seems clear that the accuracy of the vertebral ring method of determining the ages of albacore has yet to be demonstrated. It was described by Aikawa and Katô (1938) who give a table (their Table 12, "Age Determination of Fish—I") showing the range in length for albacore of various ages. The data from this table have been plotted (Fig. 17) and from that figure it may be seen that the growth increment from the age of one to that of eight is exactly the same each year, resulting in a growth curve that is absolutely linear. This is totally at variance with what is known of growth curves in general and in all other species of fishes that have been studied. If the number of "age rings" bears this relationship to the length of the fish it is probable that they do not represent annuli and bear no direct relationship to age.

Regardless of these differences it is obvious that there are important resemblances between the Japanese albacore population and that of the West Coast of North America. In other respects than that of size-group composition a resemblance

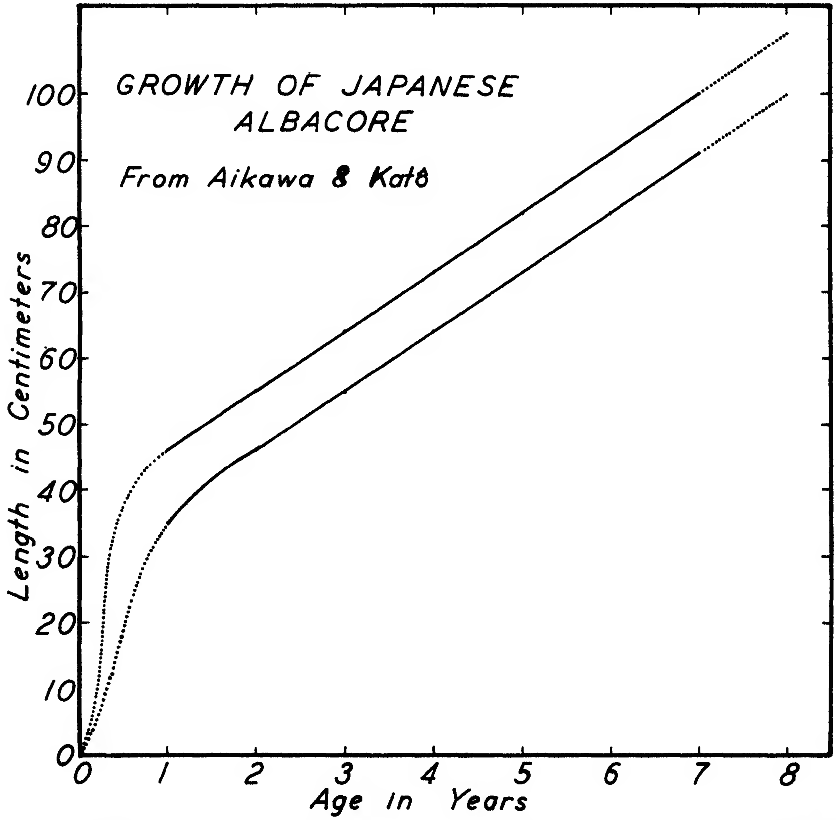

Fig. 17. Growth curve of Japanese albacore according to the data of Aikawa and Katô, 1938.

can be noted between the two fisheries. The two seasons of which published reports are available (Uno, 1936a; 1936b) were characterized by a short fishing season—from the first part of May until the end of June for 1935, and through June for 1936. The Japanese fishery is also, like the American, an offshore fishery. In most cases fishing is conducted over 100 miles from shore, from Lat. 34° to 35° N., and from Long. 142° to 145° E. Some albacore scales received from Japan were taken from fish caught during July, 1940, at about Lat. 35° N. and Long. 145° E.

While the similarities do not prove any relationship between the Japanese and American albacore populations, such as a common origin, they do suggest, at least, the existence of similar biological conditions in the stocks of fish on which the fisheries are based.

HAWAIIAN ALBACORE

The few data available concerning the albacore of the Hawaiian Islands are interesting and suggestive because of the differences shown when compared with data on the albacore from other portions of the North Pacific. The fish landed in both the Japanese and American fisheries are, from the data at hand, largely between 50 and 100 centimeters in length. The fishing seasons may begin as early as May and end as late as December. Spawning fish, or fish with ripening eggs, have apparently never been recorded from either the Japanese (Kishinouye, 1923, p. 384) or the American fisheries. The Hawaiian albacore and the fishery differ with respect to all these features.

Some indication of the sizes of the fish occurring in the Hawaiian fishery is given in a short paper by Dr. Frances N. Clark (1929). During the summer of 1929 Dr. Clark made a series of measurements on 21 Hawaiian albacore at San Pedro and found that they ranged from 39 to 46 inches (99 to 117 centimeters) in length. These fish had been shipped from the Hawaiian Islands and were part of shipments that aggregated over 43,000 pounds during the season of 1929 (Bulletin 30, California Division of Fish and Game, 1931). It is assumed that the sample was fairly representative although it is not impossible that the fish had been selected for size by the shipper. The length of these fish is, however, so much greater than those taken in the West Coast fisheries that it would be difficult to get many fish of these sizes even out of an entire season's catch in either Oregon or California. For example, in the season of 1927, when these sizes occurred most abundantly in the San Pedro fishery (Fig. 2 and Table 4), only about 2.6 per cent of the fish measured was greater than 99 centimeters in length. On this basis only about 50 pounds out of each ton would be fish large enough to fall in this range; in other words, for fish of this size there would be only about one to every ton of fish landed. It is highly improbable that the selection of fish by any commercial shipper would extend to such lengths; it is more probable that the tendency would have been to ship smaller fish—more like those ordinarily handled by the California packers. From this evidence it is quite likely that there is a real and probably great difference in the size between the albacore taken in the Hawaiian Islands and those taken along the West Coast of North America.

An estimate of the statistical significance of the observed difference may be made by calculating the probability of obtaining by chance a sample of 21 fish of the range of lengths of the Hawaiian sample (i.e., greater than 99 centimeters in length) from the California population. The assumption is made that the samples of both Hawaiian and California fish were random. It is further assumed that the proportion of fish of various sizes in the California population was the same as

that shown by the seasonal length-frequency distribution of the albacore samples for 1927, since the proportion of large fish was highest in that year (Table 4). In that season 2.63 per cent of the fish sampled at San Pedro was greater than 99 centimeters in length. The probability of obtaining a sample of 21 fish of lengths over 99 centimeters from this population is $\left(\frac{2.63}{100}\right)^{21}$ or about 10^{-33}—an exceedingly low probability.

Fowler (1928, pp. 133-134), in discussing a cast of this species in the Bishop Museum, Honolulu, T.H., which is 1083 millimeters in standard length, remarks that it is of average size. A fish of this size would certainly not be considered as average by even a casual observer of the fish caught in the eastern North Pacific.

Mr. I. H. Wilson, Director of the Division of Fish and Game, Territory of Hawaii (private communication), states that the average length of Hawaiian albacore will run close to 40 inches (100 centimeters), and the average weight to nearly 40 pounds.

The fishing season in Hawaii is apparently during the winter months, according to Mr. Wilson, but it is evidently not as definite and consistent as the seasons experienced in the American mainland fishery. There are, however, no factual data available regarding the duration and regularity of the fishing seasons.

Fish with ripening eggs are taken in the Hawaiian fishery (Clark, 1929; I. H. Wilson, private communication), and it is quite possible that spawning fish occur in Hawaiian waters. Sanzo's (1933) work on the albacore of the Mediterranean would indicate that if there were mature albacore available in any of the North Pacific fisheries, at least in those off the North American coast, they should be in ripening or spawning condition during the fishing season.

The evidence for these differences between the Hawaiian albacore and others is not as satisfactory as could be desired. However, it appears reasonably certain that they indicate either the existence of a distinct Hawaiian race or stock, or else that the Hawaiian fish are an older and more mature portion of the same population as that found in the eastern North Pacific. They may even represent the part of the population that is engaged in the essential business of reproduction.

ALBACORE OF THE MID-PACIFIC

The presence of albacore on both sides of the North Pacific and in the vicinity of the Hawaiian Islands has been discussed in previous sections. The isolation of those populations, one from the other, has been commonly taken for granted. However, evidence is introduced here that gives support to the possibility that at least an occasional interchange may occur. This evidence consists in records of offshore captures of albacore, and there are three such records available to the writer. One concerns the capture of albacore in the area between Japan and the Hawaiian Islands, and the other two, catches between the Hawaiian Islands and the West Coast of North America.

"FUJI MARU."—Aikawa and Katô (1938) give the length frequencies of 538 albacore taken from a region approximately 500 miles west of Midway Island. The fish were captured by the "Fuji Maru," a vessel of the Shizuoka Prefecture Marine Products Testing Station, within the period January to May, 1937, and within the area bounded by Lats. 28° to 34° N., and Longs. 170° to 173° E. (Fig. 18).

There are a number of modal groups in the length-frequency distribution of these fish, two of which modes are below 50 centimeters (see Table G, Appendix, and

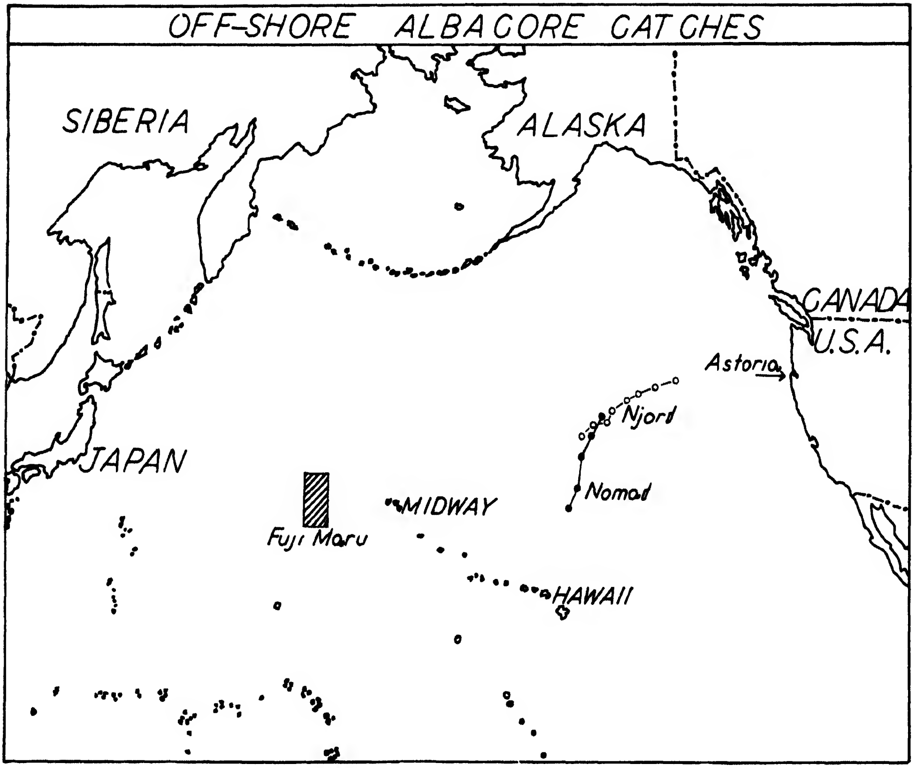

Fig. 18. Chart showing location of albacore catches in mid-Pacific. The rectangle west of Midway Island marks the position of the catches made by the "Fuji Maru" (Aikawa and Katô, 1938). The solid circles between the Hawaiian Islands and the American coast show the course over which albacore were landed aboard the "Nomad," and the open circles the course over which albacore were landed aboard the "Njord." The position given at the southern end of the "Nomad's" course is that of the initial albacore catch, and the position at the northern end of the course of the "Njord" is that of the last albacore catch of that yacht.

Fig. 19). These two groups are composed of fish shorter than any commonly taken in either the Japanese or the American onshore fisheries and the shorter of the two, with a modal length near 26 centimeters, contains albacore smaller than any recorded from American fishing grounds. Above the length of 50 centimeters there are also two well-defined modes which, in all probability, indicate the presence of two age groups. There may also be at least one additional mode at about 80 centimeters. Except for the fish less than 50 centimeters in length, this curve shows a close resemblance to the Oregon length-frequency curves both in the relative proportions of the two obvious groups and in the positions of the modes marking them.

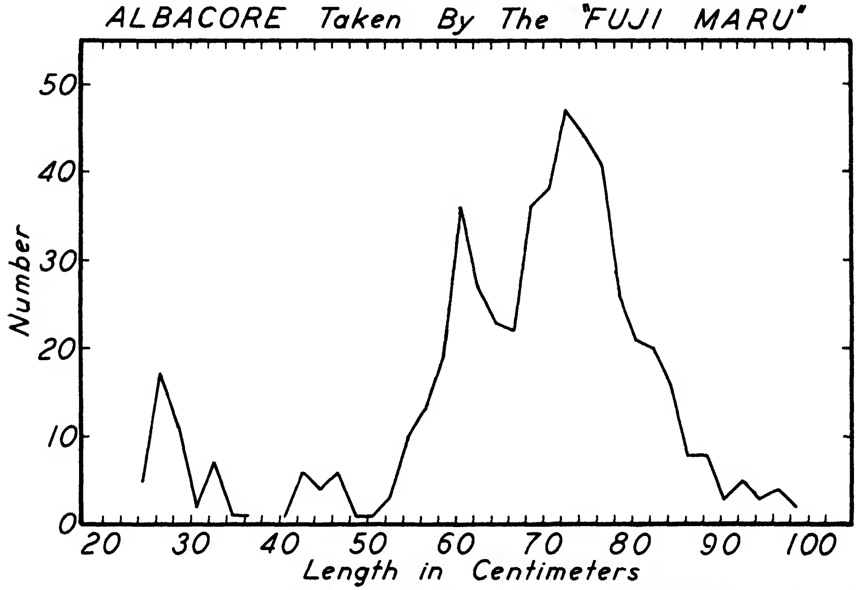

Fig. 19. Length-frequency curve for albacore taken by the "Fuji Maru." Data from Figure 7 of Aikawa and Katô, 1938.

By inference the measurements given by Aikawa and Katô were made over a period of some four months—a period long enough so that growth might well obscure the modes of the length-frequency curve. This would make it difficult to determine the modal positions by the method of fitting normal curves, as was done with the Oregon data. A similar obscuring of the modes might result from combining samples taken from different schools of fish in which the modal lengths vary, even within the same age groups, from one school to the next. It is apparent that the measurements of Aikawa and Katô have been affected by some such factor since the distribution of their group B is distinctly platykurtic when compared to that of the same group in the Oregon length-frequency distributions. The modes in the distributions of Aikawa and Katô were selected, therefore, by the method employed in the case of the California length frequencies: that of averaging the five highest classes in the vicinity of the mode. Group A has a modal length, as thus determined, of 61.0 centimeters, and group B of 72.6 centimeters.

These values are less than the corresponding Oregon modes by from two to

four centimeters (see Table 5), and the real difference would be still greater if the fish had actually been measured by means of a tape over the curve of the body instead of on a measuring board as was done with the Oregon samples. Assuming that these mid-Pacific albacore were measured by a tape, the transformation to equivalent measuring-board lengths (for method see p. 224) gives the mode of group A as 58.2 centimeters and that of group B as 69.22 centimeters. These are about 5.5 centimeters less than the corresponding Oregon modes (Table 5). If, for the sake of argument, the assumptions be made that these mid-Pacific fish were of the same brood year and had a growth rate similar to that of the Oregon fish for, let us say, 1939, it would appear that they were about two or three months younger.

"NOMAD."—Also shown on Figure 18 are albacore catches made from the yacht "Nomad" on a voyage from the Hawaiian Islands to Coos Bay, Oregon, during June, 1937, about one month later than the last catch of the "Fuji Maru" (Brock, 1939). While the fish landed on board the "Nomad" were not measured, they were, by the reliable testimony of the captain and navigator, not noticeably different from the sizes common in the Oregon commercial fishery. Although fishing was carried on continually from the time of leaving the Hawaiian Islands, the first albacore catch was made at Lat. 30° 11' N., Long. 154° 15' W. Dolphin were caught earlier and catches of this species continued until Lat. 33° N. was reached, thus overlapping the position of the first albacore catch by about three degrees of latitude. The last catch of albacore was taken at Lat. 40° 14' N., Long. 150° W., but this did not necessarily mark the eastward extension of albacore schools because fishing was discontinued for reasons other than lack of fish.

"NJORD."—In July, 1938, the yacht "Njord" made a similar voyage north and east from the Hawaiian Islands, and likewise took albacore at localities that overlap the most easterly catch taken aboard the "Nomad" (Brock, 1939). These catches continued until Lat. 44° 17' N., Long. 139° 58' W. was reached, about 550 miles off the West Coast of North America (Fig. 18). In this case also fishing was discontinued for reasons other than lack of fish.

While the albacore taken during these three voyages certainly demonstrate the presence of this species in some quantity remote from land, little else can be deduced from the time and position of these catches. Possibly an easterly migration or drift of the albacore schools is indicated, since the earliest catches, those of the "Fuji Maru," were most westerly. In general, the direction of surface water transport is from west to east in these latitudes; hence, a purposeful migratory movement of the fish does not have to be assumed. The schools of albacore may have been drifted to the eastward by these currents, provided, of course, that the directed movements of individual schools were not sustained long enough to nullify the effects of the drift.

A recent study of the hydrography of this general region (Goodman and Thompson, 1940) contains information that may have some bearing on the distribution of this pelagic fish. They found that the ocean waters between the Straits of Juan de Fuca and the Hawaiian Islands could be divided into five general regions, viz., Coastal Waters, Washington Drift, Transition Area, Northeast Pacific Stream, and East Hawaiian Water. It is suggestive that the northerly boundary of the East Hawaiian Water (Lat. 32° N., Long. 148° 30' W.) was near the position of the first albacore captures of the "Nomad." The water of the East Hawaiian Water was, at the time of the investigation, characterized by high surface water temperatures (22°-25° C.) and high salinity. The next area northeast, the Northeast Pacific Stream, had a temperature range of 18.9°-23° C. The isochlors (Fig. 12 of Goodman and Thompson, 1940) show an even more striking change than that indicated by temperature. There is a gradual increase in salinity westward from the mainland, and a

similar increase in salinity with depth as far west as station 8 (Lat. 34° 51' N., Long. 145° 29' W.). Approximately at this station the salinity was constant to a depth of 400 or 500 meters and for all stations between station 8 and the Hawaiian Islands the salinity was greatest at the surface, decreasing with depth to 500 or more meters, and thereafter increasing again. However, the salinity at 2500 meters was not as great as that at the surface for all stations from station 9 (Lat. 32° 151' N., Long. 148° 11' W.) to the Hawaiian Islands.

Station 8 was apparently near the boundary of temperate and tropical water, the first characterized by an increase of salinity with depth and the second by having water of the greatest salinity at the surface. It is not improbable that the position of this boundary is a fluctuating one and it may have been further to the southward at the time of the first albacore catches of the "Nomad."

While albacore do occur in the waters about the Hawaiian Islands, and therefore, in the tropical belt, it has already been shown that such fish seem to be larger than any of the others discussed here (p. 234). Then too, the albacore fishery is best in the Islands during the winter months, especially January and February,[3] when water temperatures are presumably lower than during the time (August) of the observation of Goodman and Thompson.

The evidence given here indicates a migratory movement of albacore across the Pacific but cannot be considered to be more than suggestive. However, the presence of these fish so far offshore makes some intermingling of the North Pacific populations likely and, if such interchanges of fish are frequent and involve large elements of the total population, regulatory measures must be applicable over the whole North Pacific Basin if they are to be effective. A thorough investigation of the migrations and breeding habits of the different populations of Pacific albacore is clearly necessary to an understanding of the biology of the species adequate to provide for its proper conservation. Such an investigation must cover the entire range of the species and will undoubtedly be difficult and costly unless it can be combined with other related oceanographic and marine fishery investigations. It is to be hoped that, eventually, a broad research program of this nature will be undertaken and that in this program a place will be provided for an adequate study of the Pacific albacore.

SUMMARY

The temperate water fisheries for albacore in the North Pacific seem to exploit somewhat similar segments of the respective populations present in the various localities. It is clear that in most of the exploited populations two or at most three year classes are highly dominant.

In the California fishery from 1924 to 1928 the population segment exploited appears to have been composed, in the main, of only two year classes. The Oregon fishery likewise has drawn upon fish belonging largely to two year classes. The Oregon length-frequency measurements resemble very closely those from California.

The range in lengths of Japanese albacore as well as the few modal groups present make it seem probable that only a few year classes were present in the Japanese landings. Although age readings by the use of vertebral rings as made by Japanese investigators are of doubtful accuracy, they show the presence of only three year classes, and only one of these in abundance. The lengths of the Japanese fish were similar to those landed in the American fisheries.

[3]This information was supplied (private communication) by I. H. Wilson, Director, Hawaiian Division of Fish and Game.

Fish with ripening ova are not present in the Oregon fishery and have never been recorded from the California fishery. Kishinouye discovered no fish with maturing reproductive elements in Japanese waters. The fish landed from the small Hawaiian albacore fishery apparently do not share these characteristics. These fish are larger and evidently do possess ripening ova. Whether smaller immature fish similar to those taken in American and Japanese fisheries are also taken in the Hawaiian fishery is not known. While it is possible that fish are only caught at times when no ripening ova are present, it is more probable that the fish taken in both American and Japanese fisheries are actually immature and have never spawned.

The available evidence, therefore, strongly suggests that only a few year classes are present in the temperate water fisheries for this species, and that these are immature. This may, at least in part, account for the history of instability shown by the California fishery and may cause a similar instability in the Oregon fishery.

The populations exploited by the North Pacific albacore fisheries may represent three different stocks or races which center off the coasts of North America, Hawaii, and Japan. However, the existence of albacore in mid-Pacific at positions roughly midway between these three localities makes it appear possible that more or less intermingling may occur. Whether or not those fish occurring offshore represent wholesale migratory movements is unknown; but if so, that fact would inevitably force the study and conservation of this species to cover the entire North Pacific Basin.

LITERATURE CITED

AIKAWA, Hiroaki, and Masuo KATÔ

1938 Age determination of fish. I. Bull. Japanese Soc. Sci. Fish., Tokyo, vol. 7, no. 2, pp. 84-87, fig.

BROCK, Vernon E.

1939 Occurrence of albacore *Germo alalunga* in mid-Pacific. Copeia, 1939, no. 1, p. 47, fig.

BULLETINS, CALIFORNIA DIVISION OF FISH AND GAME, BUREAU OF COMMERCIAL FISHERIES

1931 The commercial fish catch of California for the year 1929. Fish Bulletin no. 30, Sacramento, 135 pp.

1937 The commercial fish catch of California for the year 1935. Fish Bulletin no. 49, Sacramento, 170 pp.

1940 The commercial catch of California for the years 1936-1939, inclusive. Fish Bulletin no. 57, Sacramento, 100 pp.

1942 The commercial fish catch of California for the year 1940. Fish Bulletin no. 58, Sacramento, 47 pp.

CLARK, Frances N.

1929 A racial comparison of California, Hawaiian, and Japanese albacore *Germo germo*. Calif. Fish and Game, Sacramento, vol. 15, no. 4, pp. 351-353.

FOWLER, Henry W.

1928 The fishes of Oceania. Memoirs Bernice P. Bishop Museum, Honolulu, vol. 10, pp. iii+540, 49 pls.

GOODMAN, Joe, and Thomas G. THOMPSON

1940 Characteristics of the waters in sections from Dutch Harbor, Alaska, to the Straits of Juan de Fuca, and from the Straits of Juan de Fuca to Hawaii. Univ. Washington publ. in oceanography, Seattle, vol. 3, no. 3, pp. 81-103, and appendix, pp. 1-48, 17 figs.

KISHINOUYE, Kamakichi

1923 Contributions to the comparative study of the so-called scombroid fishes. Journ. Coll. Agriculture, Tokyo, vol. 8, no. 3, pp. 295-437, 22 pls.

RICH, Willis H.

1925 Growth and degree of maturity of Chinook salmon in the ocean. Bull. U.S. Bureau Fisheries, vol. 41, pp. 15-90, 40 figs.

SAMSON, V. J.
1940 Notes on the occurrence of albacore *Germo alalunga* in the North Pacific. Copeia, 1940, no. 4, p. 271.
SANZO, L.
1933 Uova e primi stadi larvali di Alalonga *Orcynus germo* Ltkn. R. Comitató Talassografico Italiano, Venezia, Mem. 198, 9 pp., 1 pl.
SERVENTY, D. L.
1941 The Australian tunas. Division of Fisheries Report no. 4, Melbourne, pp. 1-48, 4 pls.
SIMPSON, George G. and Anne ROE
1939 Quantitative zoology. pp. i-xvii, 1-414, 52 figs.
SNEDECOR, George W.
1934 Calculation and interpretation of analysis of variance and covariance. 96 pp. Ames, Iowa.
UNO, Michio
1936a *Germo germo* (Lacepede) in the waters east of Nozima Promontory, Tiba Prefecture. (Preliminary report.) Bull. Japanese Soc. Sci. Fish., Tokyo, vol. 4, no. 5, pp. 307-309, 5 maps, 2 figs.
1936b *Germo germo* (Lacepede) in the waters east of Nozima Promontory, Tiba Prefecture. (Preliminary report II.) Ibid., vol. 5, no. 4, p. 235, 2 figs.

APPENDIX

Table A. Length frequencies of albacore taken at San Pedro, California, by California Division of Fish and Game, 1924-1928.

(The true mid-value of the classes are higher than the figures shown in the left-hand column by 0.25 cm. for 1924 and by 0.05 for the other years. This difference is due to differences in the way in which the measurements were tabulated at the time they were received at the California State Fisheries Laboratory.)

Length in cm.	Year					Length in cm.	Year				
	1924	1925	1926	1927	1928		1924	1925	1926	1927	1928
51				1		90	49	12	16	98	4
52						91	49	6	14	86	
53				4		92	43	5	8	53	
54				4		93	40	2	2	25	
55	5			8		94	42	3	2	12	
56	2			9		95	26	2	5	14	
57	3			13		96	26		1	9	
58	4			9		97	35	1	5	9	1
59	6			12		98	22	2		6	
60	3	5		20		99	12	2		7	
61	4	4	2	25		100	7	1	1	6	
62	10	9	1	23	1	101	2			4	
63	32	14	1	44	3	102	2			4	
64	61	18	4	38	3	103	1			11	
65	102	34	8	78	11	104				4	
66	163	73	14	120	20	105				5	
67	219	96	16	169	42	106	1			15	
68	194	108	31	194	53	107				5	
69	141	91	40	192	68	108				8	
70	132	80	76	191	49	109				10	
71	91	57	71	169	40	110				4	
72	65	59	98	139	38	111	1			8	
73	69	83	86	116	26	112				5	
74	66	81	108	96	17	113				8	
75	78	131	98	59	29	114				5	1
76	159	176	123	56	25	115	1			6	
77	216	241	139	60	36	116				7	
78	311	310	134	86	34	117				3	
79	348	372	144	134	75	118				1	
80	417	388	178	178	97	119				1	
81	382	362	198	198	130	120	1			3	
82	341	361	226	246	146	121				3	
83	295	328	195	248	137	122					
84	253	234	161	283	118	123				1	
85	189	187	122	311	90	124					
86	145	138	91	273	60	125				1	
87	110	64	62	241	26	126				1	
88	69	41	45	253	14						
89	55	19	24	167	7	Totals	5,100	4,200	2,550	4,915	1,401

Table B. Albacore length measurements, Astoria, August 24, 1938.

(Measurements originally to nearest eighth of an inch.
Values tabled are mid-class.)

Length in inches	Frequency	Length in centimeters
24 1/16	5	61.12
24 9/16	22	62.39
25 1/16	22	63.66
25 9/16	28	64.93
26 1/16	39	66.20
26 9/16	22	67.47
27 1/16	24	68.74
27 9/16	9	70.01
28 1/16	10	71.28
28 9/16	5	72.55
29 1/16	6	73.82
29 9/16	4	75.09
30 1/16	2	76.36
30 9/16		77.63
31 1/16	1	78.90
31 9/16		80.17
32 1/16		
32 9/16		
Total	199	

Table C. Albacore length measurements, Astoria, Oregon, 1939.

(Measurements made to nearest eighth of an inch.
Values tabled are mid-class.)

Length in inches	Aug. 25-29	Sept. 1-6	Sept. 8-9	Sept. 27	Oct. 3-5	Oct. 17	Totals	Length in centimeters
21 1/8					1		1	53.7
21 5/8		1					1	54.9
22 1/8	1				1		2	56.2
22 5/8	4				2		6	57.5
23 1/8	11	2		1	3		17	58.7
23 5/8	8	2		1	2		13	60.0
24 1/8	23	12	2	2	3		42	61.3
24 5/8	58	18	5	5	9		95	62.5
25 1/8	75	24	17	16	19		151	63.8
25 5/8	50	26	11	10	20		117	65.1
26 1/8	18	13	9	6	23		69	66.4
26 5/8	9	8	3	1	7		28	67.6
27 1/8	18	14	6	2	5		45	68.9
27 5/8	43	23	19	1	5	1	92	70.2
28 1/8	115	77	65	2	14	6	279	71.4
28 5/8	168	105	92	5	21	9	400	72.7
29 1/8	183	163	131	8	35	19	539	74.0
29 5/8	154	140	104	11	64	23	496	75.2
30 1/8	116	128	87	9	56	28	424	76.5
30 5/8	62	60	50	8	36	18	234	77.8
31 1/8	28	24	23	1	28	16	120	79.1
31 5/8	11	12	7	1	10	4	45	80.3
32 1/8	5	4	5		7	3	24	81.6
32 5/8	5		2		3	1	11	82.9
33 1/8	3	1			2	3	9	84.1
33 5/8		2	1			2	5	85.4
34 1/8					1	2	3	86.7
34 5/8								87.9
35 1/8			1				1	89.2
35 5/8								90.5
36 1/8		1					1	91.8
36 5/8								93.0
Totals	1,168	860	640	90	377	135	3,270	

Table D. Albacore length measurements, Astoria, Oregon, July 13-21, 1940.

(Measurements made to nearest eighth of an inch.
Values tabled are mid-class.)

Length in inches	7/13-7/17	7/19-7/21	Total	Length in centimeters
20 1/8		1	1	51.11
20 5/8	2		2	52.39
21 1/8	2		2	53.66
21 5/8	6		6	54.93
22 1/8	15	3	18	56.20
22 5/8	29	7	36	57.47
23 1/8	49	11	60	58.74
23 5/8	52	18	70	60.01
24 1/8	98	13	111	61.28
24 5/8	97	24	121	62.55
25 1/8	153	29	182	63.82
25 5/8	68	19	87	65.09
26 1/8	52	11	63	66.36
26 5/8	29	9	38	67.63
27 1/8	19	10	29	68.90
27 5/8	41	16	57	70.17
28 1/8	34	17	51	71.44
28 5/8	43	25	68	72.71
29 1/8	59	23	82	73.98
29 5/8	41	32	73	75.25
30 1/8	20	14	34	76.52
30 5/8	10	10	20	77.79
31 1/8	3	5	8	79.06
31 5/8	1	2	3	80.33
Totals	923	299	1,222	

Table E. Albacore length measurements, Astoria, Oregon, July 30-October 14, 1940.

(Measurements made to nearest one-half centimeter. Values tabled are mid-class.)

Length in centimeters	July 30-Aug. 6	Aug. 14-16	Aug. 21-23	Sept. 4-6	Sept. 27-Oct. 7	Oct. 11-14.	Total
50.25							
51.25	1						1
52.25	2						2
53.25	4	1		1	1		7
54.25	2	1	1	3			7
55.25	1		2				3
56.25	4		3	1	2		10
57.25	11	3	3		1		18
58.25	19	4	6	2	2		33
59.25	12	6	3	3	1		25
60.25	11	9	10	8	2		40
61.25	13	6	7	9	2		37
62.25	23	8	9	6		1	47
63.25	28	11	26	7	3	1	76
64.25	26	10	23	14	2		75
65.25	27	19	21	13	1	2	83
66.25	14	13	21	17	6	1	72
67.25	10	8	17	10	6	4	55
68.25	13	14	19	11	2	2	61
69.25	17	12	25	12	2	1	69
70.25	25	19	15	7	5	3	74
71.25	25	24	19	9	4	2	83
72.25	47	42	27	9	1		126
73.25	46	26	39	20	8		139
74.25	34	60	42	14	6	5	161
75.25	34	32	39	18	13	9	145
76.25	18	29	28	26	15	12	128
77.25	14	17	29	21	17	16	114
78.25	5	6	20	19	20	17	87
79.25	4	3	15	16	18	15	71
80.25	1	2	8	9	16	14	50
81.25	1	4	7	6	9	12	39
82.25	1		4	3	9	6	23
83.25	3	3	3	1	7	3	20
84.25		1	5	2	3	3	14
85.25	2	2	3	1	4	2	14
86.25		2	2		5	6	15
87.25	1	1	1		3	1	7
88.25		1		2	1	1	5
89.25				1	1	2	4
90.25					2		2
.....							
98.25						1	1
Totals	499	399	502	301	200	142	2,043

Table F. Length frequencies of Japanese albacore, 1935 to 1936, as given by Uno, 1936a; 1936b.

(The true mid-values of the classes are higher than the figures shown in the left-hand column by 0.55 cm. for 1935 and by 0.05 cm. for 1936.)

Length in centimeters	1935	1936
56		1
57		1
58		
59		
60		
61		
62		3
63		2
64		3
65		1
66		3
67		0
68		2
69	4	2
70	8	6
71	20	7
72	25	7
73	64	7
74	150	5
75	136	7
76	118	8
77	109	10
78	134	9
79	140	6
80	80	7
81	133	7
82	57	11
83	78	14
84	91	15
85	64	18
86	25	12
87	18	6
88	14	6
89	6	6
90	7	1
91	5	3
92	4	2
93	4	2
94	2	
95	3	
Totals	1,499	200

Table G. Length frequencies of albacore taken by the "Fuji Maru" from January to May, 1937, in the area between Lat. 28° to 34° N. and Long. 170° to 173° E. (from Aikawa and Katô, 1938).

Length in centimeters	Number	Length in centimeters	Number
23	5	62	10
24	11	63	17
25	6	64	14
26	7	65	9
27	4	66	11
28	1	67	11
29	1	68	17
30		69	19
31	7	70	13
32	1	71	25
33		72	18
34	1	73	29
35		74	25
36		75	19
37		76	22
38		77	19
39		78	13
40		79	13
41	1	80	9
42	3	81	12
43	3	82	10
44	3	83	10
45	1	84	7
46	5	85	9
47	1	86	6
48		87	2
49	1	88	5
50	1	89	3
51		90	2
52		91	1
53	3	92	3
54	8	93	2
55	2	94	1
56	8	95	2
57	5	96	1
58	8	97	3
59	11	98	
60	15	99	2
61	21	Total	538